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UNMANNED TACTICAL AUTONOMOUS CONTROL AND COLLABORATION (UTACC) IMMEDIATE ACTIONS

by

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June 2017

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Unmanned tactical autonomous control and collaboration (UTACC) is a Marine Corps research enterprise to cultivate a system of systems (SoS) that works alongside other human team members. UTACC is being specifically designed to reduce cognitive demand on the warfighter. It will accomplish this by working with the Marines instead of working for them.

The two aims of this thesis are to (1) analyze interdependence requirements, utilizing coactive design, of a Fire Team with UTACC UxS in an immediate action drill; and (2) create a suggested list of design and implementation requirements for the UTACC SoS with specific focus on situations involving immediate actions. Resilience in this instance is incorporated by designing flexibility into the system. Interdependent relationships, described as observability, predictability, and directability, develop teamwork and provide this flexibility for the overall system. Advancements within the robotics industry have traditionally focused on autonomy so that the machine can accomplish tasks independent of others. The focus of coactive design is the creating and managing of the interdependent relationships rather than relying on the machine carrying out independent tasks autonomously. Additionally, utilization of the coactive design process provides a means of determining cost-effective development areas that will direct the way forward in developing a system that accomplishes immediate action drills for contact with the enemy.

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LIST OF ACRONYMS AND ABBREVIATIONS

COMSEC	communications security
CONOPS	concept of operations
DARPA	Defense Advanced Research Project's Agency
DOD	Department of Defense
EF21	Expeditionary Force 21
HIS	human system integration
H-M	human-machine
IA	Interdependence Analysis
IHMC	Institute of Human Machine Cognition
ISR	intelligence, surveillance, and reconnaissance
MAGTF	Marine Air Ground Task Force
MCDP	Marine Corps Doctrinal Publications
MCWL	Marine Corps Warfighting Laboratory
MCWP	Marine Corps Warfighting Publications
MOC	Marine Corps Operating Concept
MOE	measure of effectiveness
MOP	measure of performance
MUM-T	man-unmanned teaming
NIST	National Institute of Standards and Technology
NMC	non-mission capable
NPS	Naval Postgraduate School
NVG	night vision goggle
OPD	observability, predictability, directability
QRF	quick reaction force
RAS	robotic autonomous systems
RF	radio frequency
SOP	standard operating procedure
SoS	system of systems
SOW	statement of work
TTP	tactics, techniques, and procedures

UAS	unmanned air system
UAV	unmanned air vehicle
UGS	unmanned ground system
UGV	unmanned ground vehicle
USMC	United States Marine Corps
UTACC	Unmanned Tactical Control and Collaboration
UxS	unmanned system in general

EXECUTIVE SUMMARY

Unmanned Tactical Control and Collaboration (UTACC), sponsored by Marine Corps Warfighting Laboratory (MCWL), is an effort to develop future man-machine systems for deployment on the battlefield. The newly published Marine Corps Operating Concept (MOC) identifies areas where we should exploit automation and places emphasis on efforts to cultivate man-unmanned teaming, integrating robotics into Marine Corps structure where possible. The end state of these efforts is to improve upon the current team and create better warfighting capabilities. The work in this thesis is focused on the interdependencies within a Marine Corps four-man fire team using the coactive design method to reveal overall requirements for the functioning of that team. Coactive design is a human-machine design method that focuses on utilization of interdependent relationships to complete tasks. When a human and a machine are working together to complete a task the human is more capable in some areas while the machine is more capable in others. For example the human may be more efficient at route planning yet the machine has better situational awareness if you allow the machine to provide the human with a complete situational awareness picture the human can create a route for the team. This is the basic idea behind coactive design, to correctly team man and machine for the most efficient and effective arrangement in contrast to efforts involving autonomy and self-sufficient systems. Once interdependent relationships are identified they are broken into three categories: observability, predictability, and directability (OPD). These three areas direct the design team where to direct time and resources on the front end to create a successful system on the back end.

Specifically, this thesis involves a Marine Corps fire teams' reaction to enemy contact. Marine Corps doctrine establishes guidelines for infantry units and their employment on the battlefield. Using doctrine to analyze the teams' reaction to enemy contact we were able to break down the interactions between team members and develop OPD requirements. Enemy contact situations are dangerous, dynamic, and rapid and therefore require fast paced responses. Our research highlighted areas that would be beneficial for the incorporation of current robotic systems, areas that require more

resources to develop in order to be beneficial, and provide for concepts that may change the scope and therefore allow for better employment of robotic systems into Marine Corps units.

References

Zach, M. (2016). *Unmanned tactical autonomous control and collaboration coactive design*. (Master's thesis). Naval Postgraduate School. Retrieved from Calhoun http://calhoun.nps.edu/handle/10945/49417

I. INTRODUCTION

Our thesis is the ninth in a series of thesis efforts that support the Marine Corps Warfighting Laboratory's (MCWL) Unmanned Tactical Autonomous Control and Collaboration (UTACC) system. MCWL's mission is to "rigorously explore and assess Marine Corps service concepts using an integral combination of war gaming, concept-based experimentation, technology assessments, and analysis to validate, modify, or reject the concept's viability, and identify capability gaps and opportunities, in order to inform and for future force development" (MCWL, 2017). The UTACC research effort has evolved and began by developing a concept of operations. Then researchers conducted a "red Team" critique of those CONOPS. Next, UTACC efforts focused on exploring Marine-machine interdependence, followed by the development of measures of performance and measures of effectiveness needed to evaluate UTACC. Another exploration effort created an analysis of alternatives for considerations for UAVs that UTACC might utilize to demonstrate the concept. Current research is focused on human-machine integration, measures of performance, and measures of effectiveness. This thesis will explore various interdependence requirements for UTACC when a Fire Team with UTACC UxS initiates immediate action drills for contact with the enemy.

A. UTACC CONCEPT

As information technology becomes ubiquitous on the battlefield, the danger of information overload arises. Simply put, there are so many ways to collect information the main problem he or she faces is how to process the information in a timely fashion and what to do with it once it is processed. More often than not when a new piece of technology is introduced, the demand on the individual leader is increased, which has the potential to diminish returns and lead to combat ineffectiveness.

UTACC was conceived and is being designed specifically for the purpose of reducing cognitive demand on the warfighter. It will accomplish this by developing unmanned systems that work *with* the Marines instead of working for them. Collaborative autonomy is a simple concept that requires immense complexity to make into a reality. It

is not enough to simply create a robot that can follow orders; we must also take into consideration the interaction between that robot and the human collaborator, otherwise known as human system integration (HSI). Considering the fact that the UTACC system will be integrated into a small unit fire team at first, we must also consider the missions it might be asked to perform, wireless technology and data transfer considerations, combat ruggedness, and operational context, just to name a few. The different elements of UTACC include the primary operator, a series of Unmanned Ground Systems (UGS), and Unmanned Aerial Systems (UAS) all working together to accomplish the mission while reducing the amount of input required from the operator.

B. RESEARCH QUESTION

This thesis attempts to provide results for two related aims. The first is to use the coactive design model to analyze interdependence between Marines in a fire team and the UTACC UxS during immediate action drills following contact with the enemy. The second is to provide recommended design requirements for a resilient UTACC UxS capable of executing immediate action drills without burdening the other Marines in the team.

C. RELATED WORK

Our thesis in a successor to and complements other theses that make up the research efforts of the UTACC program. Zach (2016) was the predecessor for the work contained within and served as a guiding source document for this thesis. Efforts by Kulisz and Sharp, currently in progress, discusses measures of performance (MOPs) and measures of effectiveness (MOEs) for human and machine integration. The work of Tschirley and Beierl, also currently in progress, examines UTACC situation awareness. Collectively, these works have contributed to the themes and analysis in this thesis.

Johnson's (2014) doctoral dissertation on coactive design and interdependence analysis served as the foundation of the research conducted in this thesis. Johnson's work provided the analytical model for coactive design and the Interdependence Analysis Tables used in evaluating situations where man-unmanned teaming (MUM-T) was present. We used Johnson's construct and Zach's (2016) adaptation to create a modified

interdependence analysis table to examine man-machine teaming relationships native to the Marine Corps fire team.

D. UTACC'S BENEFIT FROM COACTIVE DESIGN

Being a complex system revolving around human-machine relationships, UTACC gleans valuable data from the use of coactive design. Using the results of the analysis conducted, MCWL can methodically implement design changes for the progression and development of UTACC. The IA table breaks down tasks in a hierarchical manner evaluating relationships and detailing man-machine requirements. The derived requirements guide design and implementation of the system (Johnson, 2014).

E. CHAPTER SUMMARY

The goal of this chapter was to introduce the UTACC concept and conveyed its importance in the Marine Corps Operating Concept (MOC). MCWL will see advancements in development and implementation when coactive design is further implemented into UTACC. Additionally, our thesis utilizes previous research efforts to compound future design implementations. The primary outcome of this thesis is to generate recommended design investments to produce an unmanned system that can execute the tasks necessary to become a part of the four-man fire team.

Johnson's (2014) research and implementation of coactive design and interdependence analysis are the keystone to the analysis conducted in this thesis. His work and other contributions from other researchers are detailed in the following chapter.

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II. LITERATURE REVIEW

A. UNMANNED TACTICAL CONTROL AND COLLABORATION

Unmanned Tactical Control and Collaboration (UTACC) is a human-machine teaming construct under current development sponsored by the Marine Corps Warfighting Laboratory (MCWL). The important role UTACC plays into MCWL's efforts to explore innovative technologies and systems is that of furthering innovative research as directed in the Marine Corps Operating Concept (MOC). The MOC's purpose is to shape the Marine Corps' thoughts and actions to influence the development of the next generation of the Marine Air Ground Task Force (MAGTF). The analysis provided by this thesis furthers MCWL's vision and mission in meeting the requirements of the Marine Corps' next generation of warfare.

While simultaneously providing new system capabilities, research in this arena is designed to reduce the burden on mental decision-making processes within traditionally all human Marine fire teams. Using unmanned systems not only reduces the mental overload on the humans but also provides significant added value to pre-existing Marine Corps capabilities. The design requirements aimed at achieving both previously stated goals, are derived from Johnson's (2014) coactive design method by identifying mutual activities between humans and machines working toward accomplishing the same task. The process dissects high order complex processes into basic capacities that can then be implemented using algorithms into coded routines and sub-routines used to determine robotic behavior.

B. UTACC STATEMENT OF WORK OVERVIEW

The Marine Corps Warfighting Laboratory's (MCWL) desired outcome for the UTACC project is to develop a system of systems (SoS) that works mutually with the human members of a four-man fire team. The primary objective of UTACC is to create a decentralized multi-UxS manager. This manager would enable UxSs to act collaboratively within and across domains, and team with manned operations so that these UxSs can fulfill each of the roles of USMC Fire Team members (Naval

Postgraduate School [NPS] & MCWL, 2016). Within the SOW, MCWL has laid out the following assumptions that were used in our research:

> The complete UTACC system is defined to mean an armed USMC Fire Team conducting military operations with collaborative semi-autonomous UGSs (and potentially also UASs) performing all of the duties of at least one member of the fire team.
>
> UTACC is designed to be scalable. This implies any set of unmanned systems and Marines, with any mission, terrain, and environment combinations. The performer expects assistance from MCWL in defining the initial mission, terrain, and environment requirements.
>
> All functionality is to be distributed in parallel, such that the loss of one entity does not inhibit the ability of any other to continue the mission. (NPS & MCWL, 2016, p. 1)

Using the above assumptions, MCWL tasked our research to study the interdependence of human and machine systems for a Marine Corps infantry fire team and develop tables in accordance with Johnson's (2014) doctoral dissertation.

C. THE MARINE CORPS OPERATING CONCEPT (MOC)

Published in September 2016, The Marine Corps Operating Concept serves as the Marine Corps future vision, replacing the Expeditionary Force 21 (EF21) concept. The Commandant of the Marine Corps unashamedly states in the MOC that "We have not been able to adapt at the rate of change required to ensure our success in future conflict" (USMC, 2016, p. 8). MOC also states "Our ability to successfully execute the concept will depend greatly on the extent to which we have learned how to use unmanned systems and automation at all echelons and in every domain because mastering the man-machine interface offers a revolution in military operations" (USMC, 2016, p. 9). UTACC demonstrates the Marine Corps' ability to grow in the man-unmanned teaming (MUM-T) domain of warfare in line with the MOC's challenge to innovators.

The MOC describes robotics' future role in a section detailed as Exploiting Automation, placing emphasis upon three areas:

- Refine the concept of manned-unmanned teaming (MUM-T) to integrate robotic autonomous systems (RAS) with manned platforms and Marines.

- Develop CONOPs that support and embrace RAS as a critical enabler.
- Develop unmanned reconnaissance and surveillance systems to investigate littoral environments and complex terrain features (sewers; tunnels; subways; buildings; caves; etc.). (USMC, 2016, p. 16)

This paper provides additional insight on how UTACC assists the first of these critical areas. The success of the UTACC program and the Marine Corps integration of RAS would be ensuring that the machine does not increase, but instead limits or reduces the amount of cognitive load of the Marine-robot team.

The challenge issued to innovators is to “leverage technology and ideas to make us faster smarter and more lethal” (Neller, 2017). The MOC emphasizes the need to “incorporate as quickly as possible unmanned sub-surface ground and air vehicles across the MAGTF to enhance survivability, increase lethality, and reduce manpower requirements” (USMC, 2016, p. 22).

D. MARINE CORPS WARFIGHTING PUBLICATION (MCWP) 3-11.3, *SCOUTING AND PATROLLING*

1. Purpose of a Patrol

The purpose of a patrol is to gain, for the commander, “current information about the enemy and the terrain to employ the unit effectively” (USMC, 2000, p. 8-1). A patrol can also be utilized to “destroy enemy installations, capture enemy personnel, perform security missions, or prevent the enemy from gaining information” (USMC, 2000, p. 8-1). As such, “active patrolling by numerous small groups is needed to locate the enemy and gather information on the enemy's disposition, strength, morale, and weapons, as well as gather and confirm information about the terrain” (USMC, 2000, p. 8-1). While patrolling, the unit may encounter the enemy at any moment.

2. Enemy Contact

Contact can initiate through ambush, meeting engagement, or observation. Doctrine states that “an ambush is a surprise attack from a concealed position” (USMC, 2000, p. 11-7). Ambushes are classified into two groups: *near ambush* and *far ambush*. A *near ambush* is one where the enemy position is less than fifty meters from the patrol,

where a *far ambush* is greater than fifty meters from the patrol. Meeting engagement "occurs when a moving force, incompletely deployed for battle, engages an enemy at an unexpected time and place. It is an accidental meeting where neither the enemy nor the patrol expect contact and are not specifically prepared to deal with it" (USMC, 2000, p. 11-7). Observation is when the patrol encounters the enemy yet the enemy is unaware of the patrol (USMC, 2000). This observation can occur using any of the senses as well as technologically augmented abilities. For example, a patrol may see or hear an enemy force in normal context or, using night vision googles (NVG), observe the enemy in darkness.

3. Immediate Actions

The Marine Corps provides a clear definition and purpose for immediate actions:

> Immediate actions are designed to provide swift and positive reaction to visual or physical contact with the enemy. They are intended to be simple actions in which all Marines are trained. Minimal signals or commands are required and are developed as needed for the combat situation. It is not feasible to attempt to design an immediate action drill to cover every possible situation. It is better to know the immediate action drill for each of a limited number of situations that may occur during a patrol and apply them adeptly. (USMC, 2000, p. 11-7)

During these engagements, fleeting reaction time and close proximity to danger drives the correct selection of a response. When integrating robotic systems into immediate action scenarios time will be a major factor in design requirements. The machine will not have time to be aided in decisions or be provided the luxury of second attempts.

When a patrol is ambushed, the appropriate immediate action drill to be utilized first requires classification into near or far ambush. The category near or far, as categorized by doctrine, is determined by distance. If the enemy position is less than fifty meters from the patrol, it is a *near ambush*. If the enemy position is farther than fifty meters away, it is a *far ambush*.

> In a near ambush the unit in the kill zone is under very heavy, highly concentrated, close range fires. There is little or no time for those members to maneuver or seek cover. The longer the team is in the kill

> zone the more likely they will become casualties. Under near ambush conditions the immediate action is to assault without order or signal directly into the enemy's ambush position. This action moves the Marine out of the kill zone, prevents other elements of the ambush from firing on them without risking firing upon their own forces, and provides positions from which further actions can be taken. (USMC, 2000, p. 11-9)
>
> In a far ambush, the kill zone is also under very heavy, highly concentrated fires at a greater range. This greater range provides members in the killing zone maneuver space, greater time for decisions and directions, as well as an opportunity to seek cover at a lesser risk of becoming a casualty. If attacked by a far ambush, members in the killing zone, without order or signal, immediately return fire, take the best available positions, and continue firing until directed otherwise. The assault is continued against the enemy or until the order to break contact is given. (USMC, 2000, p. 11-8)

The above immediate action drills deal only with enemy ambush scenarios. Different immediate action drills are conducted for the other contact situations.

During a meeting engagement scenario, there are a few options for immediate actions. In this situation, the patrol leader may decide to utilize a hasty ambush. A hasty ambush is an immediate action drill for dictating contact upon the enemy thereby seizing the initiative.

> When the signal HASTY AMBUSH is given (by the point member, patrol leader or another authorized patrol member), the entire patrol moves quickly to the right or left of the line of movement, as indicated by the signal, and takes up the best available concealed firing position. The patrol leader initiates the ambush by opening fire and shouting, "FIRE"; thus ensuring initiation of the ambush if the weapon misfires. If the patrol is detected before this, the first member aware of detection initiates the ambush by firing and shouting. The patrol leader may decide not to initiate the ambush in order to avoid contact unless the patrol is detected. (USMC, 2000, p. 11-7)

In a hasty ambush situation the team members must immediately recognize, transmit, and take correct actions upon the signal without question. There is no time or space allowing for mistakes in action or communications.

The immediate action of assault is a common response to enemy contact for Marines. They are indoctrinated throughout training to be biased for action and aggressive in nature. Assaulting the enemy is an effective response under certain conditions. *Immediate Assault* is an immediate action drill that is used:

> defensively, to make and quickly break undesired but unavoidable contact (including ambush), and offensively to decisively engage the enemy. When used in a meeting engagement, members nearest the enemy open fire and shout, “CONTACT,” followed by the direction of the incoming attack: FRONT, LEFT, REAR or RIGHT. The patrol moves swiftly into line formation and assaults. (USMC, 2000, p. 11-8)

Furthermore doctrine discusses when contact can and will be broken depending on given requirements during both defensive and offensive situations. When used as a defensive action: “The assault is stopped if the enemy withdraws and contact is broken quickly. If the enemy stands fast, the assault is carried through the enemy positions and movement is continued until contact is broken” (USMC, 2000, p. 11-8). As an offensive action the enemy is decisively engaged and the patrol will continue in its’ assault and “escapees are pursued and destroyed until orders to break contact are given by the patrol leader” (USMC, 2000, p. 11-8). This concludes the immediate action of assault; another potential immediate action drill is to *break contact*.

Breaking contact can be accomplished in various ways. “Fire and maneuver is one means to break contact. One portion of the patrol returns the enemy fire while another portion moves by bounds away from the enemy. Each portion of the patrol covers the other by fire until contact is broken by all” (USMC, 2000, p. 11-8).

Another method to *break contact* with the enemy is covered in Marine Corps doctrine. The clock method is described as:

> Twelve o'clock is the direction of movement of the patrol. The patrol leader shouts a direction and a distance. For example: “TEN O'CLOCK-TWO HUNDRED,” means the patrol should move in the direction of ten o'clock for 200 meters. Patrol members keep their same relative positions as they move so the original formation is not disrupted. Subordinate leaders must be alert to ensure that the members of their elements and teams receive the correct order and move as directed. (USMC, 2000, 11-8)

Under the observation of the enemy scenario, the team leader will decide whether to engage the enemy or *break contact* depending on the situation and mission requirements. The patrol will engage using one of the assault methods listed above or *break contact* using the most suitable method. Depending on the overall patrol mission and the disposition of observed enemy force, the team leader will make an appropriate decision.

E. SYSTEMS ENGINEERING PROCESS

Systems engineering is a well-known process to aid in the successful development of highly complex systems. The more complex a system the more a methodical design approach is necessary to develop quality system requirements. Continuous, open channels between developers and requirement drivers are mandatory throughout development. Comparison of requirements with current technological capabilities along with available resources leads to reasonable and achievable requirements. The developed requirements are then used as a benchmark for system development. Coactive design was utilized to produce design recommendations for the future implementation of a machine in the Marine Corps fire team. More specifically this thesis focuses on the fire teams' reaction to enemy contact.

F. COACTIVE DESIGN METHOD

Johnson's (2014) dissertation on coactive design brought a fresh perspective to the field of human-robot system design. Johnson states that coactive design is "a design method based on the concept of interdependence. It makes use of a design tool called the Interdependence Analysis (IA) table" (Johnson, 2014, p. 9). The IA table details interaction between team members, both robotic and human, to illuminate the requirements for successful operation of a team. These derived requirements aid in the planning and design of systems and also to "guide the implementation which provides the teamwork infrastructure" (Johnson, 2014, p. 9).

1. Interdependence

Interdependence is the dependence of two or more people or things on each other. As Johnson (2014) stated: “understanding the nature of the interdependencies among groups of humans and machines provides insight into the kinds of coordination that will be required. Indeed, we assert that coordination mechanisms in skilled teams arise largely because of such interdependencies” (p. 53). This implies that successful teams involving human’s and machines cooperatively working together can do so because each member of the relationship contributes to the interaction (Johnson, 2014).

Johnson (2014) states that any joint activity involving a human and machine, requires an understanding of both self-sufficiency and self-directedness (autonomy). A balance of autonomy must be struck to maximize the full potential of the system. Maturing systems in the development of robotic systems naturally progress from dependent to independent before achieving the desired state of interdependent. Johnson’s assertion to the importance of interdependence can be understood in his summary of the requirement of interdependence for sophisticated tasks. “While awareness of interdependence may not be critical to the initial stages of system development, it becomes an essential factor in the realization of a system’s full potential” (Johnson, 2014, p. 47). To achieve the desired end state for UTACC, understanding interdependence is paramount to a successful system.

2. Coactive System Model

The coactive design model focuses on the effective and efficient teaming of man-machine systems. It develops interdependence requirements directing designers in their efforts.

A human may effectively assist the robot in perceptual or cognitive decisions by means of a user interface (UI) was a concept developed by Fong (2001). The model Fong (2001) developed was more suited for individual activity depicting how simple tasks were handed off from human to robot, vice modeling joint activities and the interdependencies throughout this interaction. Fong’s (2001) model therefore was more analogous to that of remote control of a robot by a human vice the Johnson et al. (2014)

model, which focused on the interdependent relationship of a joint activity. Johnson et al. (2014) model focused on pairing one team members' strength with the others' weakness to create a more effective and efficient team. The Johnson et al. (2014) model is constructed similarly to Fong's (200l) yet retains differences in its' analysis of joint activity and derived requirements of observability, predictability. and directability (OPD). This model is depicted in Figure l.

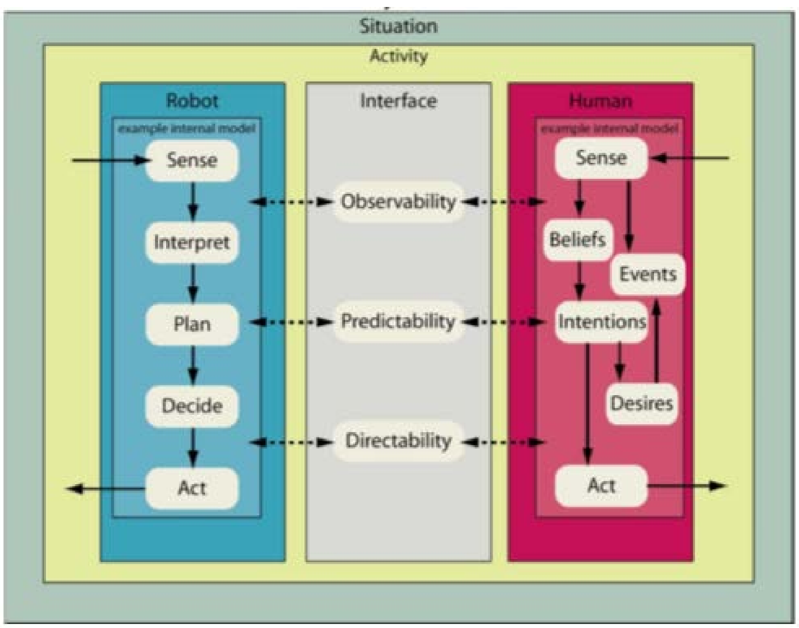

Figure 1. Coactive System Model. Source: Johnson (2014).

3. Observability, Predictability, and Directability

A key aspect of the coactive design method is the understanding of the relationship between interdependence and observability, predictability, and directability. Johnson (2014) further defines the observability, predictability, and directability:

> Observability means making pertinent aspects of one's status and knowledge of the team, task and environment observable to others. Observability also involves the ability to observe and interpret pertinent signals. It plays a role in many teamwork patterns e.g., monitoring progress and providing backup behavior.

> Predictability means one's actions should be predictable enough that others can reasonably rely on them when considering their own actions. Predictability also involves considering other's actions when developing one's own. It is essential to many teamwork patterns such as synchronizing actions and achieving efficiency in team performance.
>
> Directability means one's ability to direct the behavior of others and complementarily by directed by others. It includes explicit commands such as task allocation and role assignment as well as subtler influences, such as providing guidance or suggestions or even providing salient information that is anticipated to alter behavior, such as a warning. Teamwork patterns that involve directability include such things as requesting assistance and querying for input during decision making.
>
> By using the OPD framework as a guide, a designer can identify the requirements for teamwork based on which interdependence relationships the designer chooses to support. The framework can help a designer answer questions such as 'What information needs to be shared,' 'Who needs to share with whom,' and 'When is it relevant.' The goal of the designer is to attain *sufficient* OPD to support the necessary interdependent relationships. (2014, pp. 68–70)

Using these definitions, we can use the OPD framework as evaluation criterion in designing aspects of teaming. The OPD framework provides critical insight on how the changing of a component (structural or algorithmic) can change the interdependence relationships between the members and therefore change the overall performance of the task (Johnson, 2014).

4. Coactive Design Method

To correctly explain theoretical notions like collaboration to a system designer, an effective model and method must be used to provide clarity. The coactive design method accomplishes this by analyzing interdependent relationships and creating OPD requirements lists. These requirements can be communicated to all stakeholders and serve as the basis for design of system processes. Figure 2 represents the logical flow of the coactive design method.

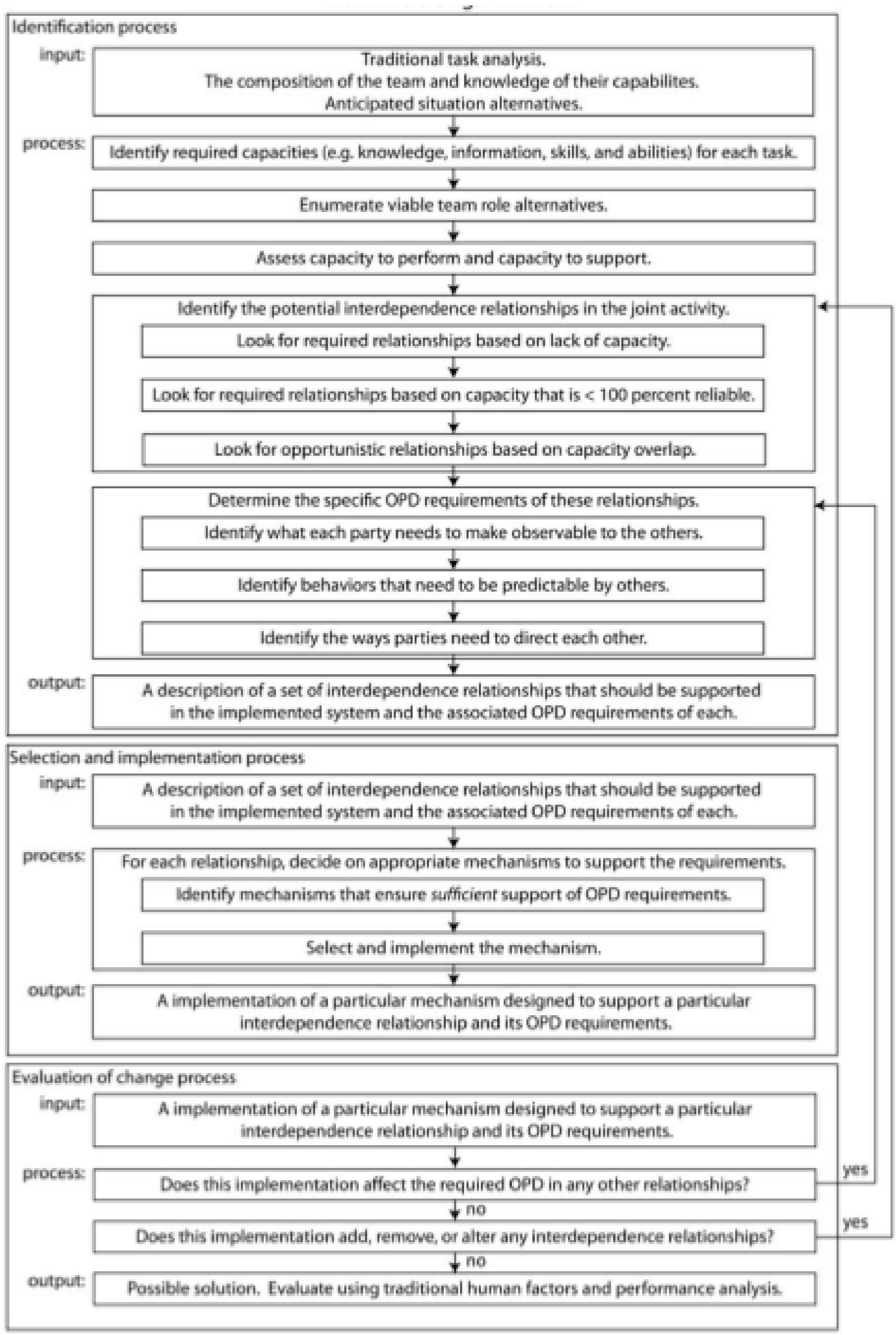

Figure 2. Coactive Design Method. Source: Johnson (2014).

The figure displays three main processes: identification, selection and implementation, and evaluation of change. A cursory overview of the process in Figure 2 shows a stepwise fashion depicting a typical cascading design process. This design process is used when requirements are understood upfront and allow developers to move from one section to the next without any requirement to reevaluate the previous section whatsoever (Satzinger, Jackson, & Burd, 2012). It is important to note feedback loops are contrary to the seemingly blocked waterfall linear process. These feedback loops illustrate the iterative nature of coactive design vice the sequential nature of the waterfall process, which is what Satzinger et al. (2012) considers a version of spiral modeling. These feedback loops further illustrate how the identification, selection and implementation, and evaluation processes require repetition to thoroughly capture interdependent activity making the coactive design process a more responsive method.

a. Identification Process

Johnson (2014) proposed an analysis tool called the Interdependence Analysis (IA) Table depicted in Figure 3. This tool is like other researcher’s task analysis techniques however is expanded to include ways of designing for interdependence by including the following:

- Allowing for soft constraints
- Allowing for more types of interdependence than just task dependency
- Representing other participants in the activity by name or by role
- Allowing for assessment of capacity to perform
- Allowing for assessment of capacity to support
- Allowing for consideration of role permutations (Johnson, 2014, p. 74)

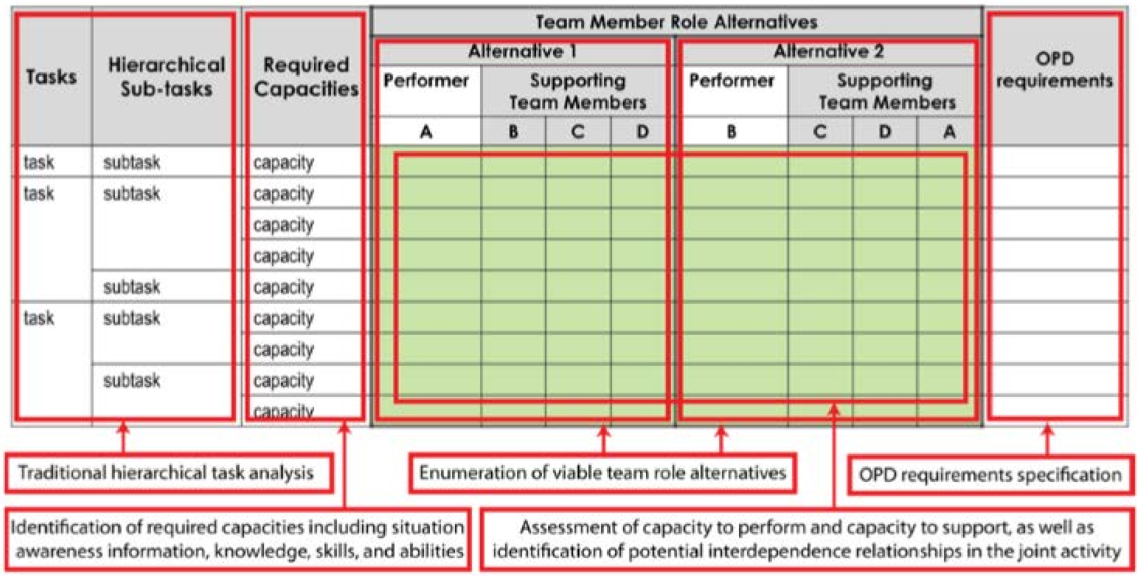

Figure 3. Interdependence Analysis Table. Source: Johnson (2014).

The coactive design method shown in Figure 2, offers broad direction for the manipulation of the more specific IA Table depicted in Figure 3. This process begins with an analysis and identification of the hierarchical manner of task and subtasks. Once task and sub-tasks are correctly identified and broken down to the appropriate level, required capacities used to complete these tasks are listed. Capacities can be competences or knowledge that the performer uses to accomplish the listed tasks. The next sections, moving left to right across the table, are concerned with the different permutations of teaming combinations. These sections are organized by identifying the performer attempting to accomplish the task and team members that support the performer. The subsequent alternatives rearrange the teaming relationships by designating a new performer and filling in the supporting team members. Analyzing alternatives identifies and communicates different requirements based on different roles. In the furthest right section a color scheme, shown in Figure 4, is used to assess the performer's ability to complete the required capacity and the supporting member's ability to assist that performer (Johnson, 2014).

Team Member Role Alternatives	
Performer	Supporting Team Members
I can do it all	My assistance could improve efficiency
I can do it all but my reliability is < 100%	My assistance could improve reliability
I can contribute but need assistance	My assistance is required
I cannot do it	I cannot provide assistance

Figure 4. Interdependence Analysis Coloring Scheme. Source: Johnson (2014).

It is not always apparent at first and is important to understand that colors denote different meanings when representative of the performer or the supporting member. While the performer column's color relates to the performer's ability to complete the listed task, the colors in the supporting member column indicate the supporting member's potential to assist the performer in that task. While green in the performer column denotes "I can do it all" and red it the supporting team member column is red signifying "I cannot provide assistance," the task is still able to be completed. The supporting member column is solely based on supporting the performer and not at all with that individual's ability to complete the task. A simple example of how the differences play out may illustrate the point further. As stated by Zach (2016), "The robot may be able to search a room while looking for an object all on its own. However, introduce a tall table into the room and place the object on it, out of view of the robot, and the robot is unable to complete the task with 100 percent reliability. Having a human check the table would improve that reliability. Shading in the IA Table would then color the performer column with yellow and the supporting column with yellow" (p. 26).

The resulting color combinations are meant to be further analyzed upon completion to provide designers interdependence requirements of the supported-supporting relationships (Johnson, 2014). Some of the possible color combinations and their interpretations are depicted in Figure 5.

Team Member Role Alternatives		Interpretation
Performer	Supporting Team Members	
A	B	
Reliable	Soft Interdependency	Independent operation by performer is a viable option, but assistance could improve efficiency.
		Independent operation by performer is a viable option, but assistance could improve reliability.
	Must be independent	Independent operation by performer is necessary.
Potential Brittleness	Soft Interdependency	Performer is < 100 percent reliable, but assistance could improve efficiency.
		Performer is < 100 percent reliable, but assistance could improve reliability.
	Must be independent	Performer is < 100 percent reliable, and no assistance is possible from this team member.
Missing Some Capacity	Soft Interdependency	Performer requires assistance, team member can provide it, and assistance can improve efficiency.
		Performer requires assistance, team member can provide it, and assistance can improve reliability.
	Hard interdependency	Performer requires assistance, and team member can provide it.
Unachievable		Performer requires assistance, but none is possible.
		Performer cannot do task.

Figure 5. Potential Interdependence Analysis Table Color Combinations with Interpretations. Source: Johnson (2014).

Johnson (2014) illustrates how correctly analyzing the color associations provide insight on the interdependence of the system as depicted in the following quote:

> Overall, the colors in the first column provide an understanding of how the performer would fare if required to meet the capacity requirement autonomously. Colors other than green in the performer column indicate some limitation of performer, such as potential brittleness due to reliability (yellow), hard interdependency due to lack of capacity (orange), or just a complete lack of capacity (red).
>
> The supporting team member columns provide an understanding of what type of interdependence relationships could potentially be supported. The color red in these columns indicates that there is no chance for assistance. This makes the performer a single point of failure. If the performer is less than 100 percent reliable, you will have a brittle system. However, if you can provide support for interdependence then you can avoid the single point of failure. Colors other than red in the supporting team member column indicate potential required (orange) or opportunistic (yellow and green) interdependence relationships between team members. The hard interdependencies are usually easy to identify because you cannot complete the task without it. Soft interdependencies tend to be more subtle, but provide valuable opportunities for teamwork and alternative pathways to a solution. (2014, p. 77)

The accurate analysis of color combinations can identify repeatable patterns within the listed teaming and support relationships. It now becomes increasingly simple to identify the below items assisting in the design process and resource allocation Johnson (2014). OPD requirements are then derived from the identified interdependencies as well as how the system responds to these questions:

- Who needs to observe what, from whom?
- Who needs to be able to predict what?
- How do members need to be able to direct each other? (Johnson, 2014, p. 57)

After the successful completion of the identification process we move into the selection and implementation process, which involves locating possible design mechanisms capable of fulfilling requirements obtained in the earlier identification process. Following the selection and implementation process is evaluation of change which ensures the mechanisms chosen in the previous process meets the requirements and that no unintended negative effects on other OPD relationships occur after implementation. Continuous feedback loops are indicative of the spiral design process as described by Satzinger et al. (2012). If, during the evaluation process, new and or different OPD relationships appear they require inclusion into the original identification process further requiring the repetition of the coactive design method. The goal of the complete process is the successful completion by all the perceived possible permutations of performance and integration tests.

G. CHAPTER SUMMARY

This chapter reviewed pertinent literature for this thesis. It began with identifying pertinent information within the MOC which stated the need for continuing the research focusing on integrating MUM-T technologies. The most influential document used in our thesis was Marine Corps Doctrine Scouting and Patrolling (USMC, 2000) which directly identifies Immediate Actions upon contact with the enemy. The second was Johnson's (2014) coactive design method, including more applicable and specific focus on the coactive design and the OPD requirements derived from interdependence analysis tables.

III. RESEARCH METHODOLOGY

The Marine Corps Warfighting Laboratory (MCWL) futures section website lists, as a sub-section to one of their mission essential tasks, to "Develop Ideas, Influence Concepts and Inform Capability requirements of future force" (MCWL, 2017). This effort has led to various research projects, and in 2013, MCWL began investigating the Unmanned Tactical Autonomous Control and Collaboration (UTACC) initiative. Research efforts by Naval Postgraduate School (NPS) students Rice et al. (2015) and Batson and Wimmer (2015) were completed early in the UTACC effort. This thesis is a continuation of previous work and, more specifically, an application of the coactive design model recommended by Zach (2016) to one section of the overall UTACC concept. It should be noted that the UTACC concept has changed throughout development from multiple unmanned systems aiding a reconnaissance team and is now focused on the integration of an unmanned ground system (UGS) with a Marine Corps fire team.

Zach (2016) researched coactive design and its application to the UTACC concept providing favorable recommendations for its implementation. All previous UTACC research was focused on teaming of unmanned ground and aerial platforms with Marine Corps forces to aid in intelligence, surveillance, and reconnaissance (ISR) efforts on the battlefield. This effort was meant to assist a reconnaissance team in its mission and enhance the overall capabilities of that team. This thesis is concerned with the current UTACC concept: replacing one member (the automatic rifleman) of a Marine Corps four person fire team with a UGS. This thesis involves the application of coactive design to a specific set of actions, labeled immediate actions, taken by the team upon contact with the enemy.

A. MODIFICATION OF THE COACTIVE DESIGN PROCESS FOR UTACC

Zach (2016) modified the coactive design Method for application to UTACC. The original Design Method proposed by Johnson (2014), shown in Figure 6, was meant to examine one humanoid robot and its interaction with humans throughout a series of tasks.

This concept was modified by previous researchers to allow application to alternative teaming roles and additional unmanned systems driven by implementation of the UTACC concept at that time. Current UTACC scope drives fewer modifications for implementation. The author of the coactive design method was consulted and any changes or modification made were agreed upon by all parties in order to enable the most efficient application as it applied to current UTACC requirements. Figure 7 shows a sample of the Interdependence Analysis (IA) table and provides an explanation of the different sections of the IA table.

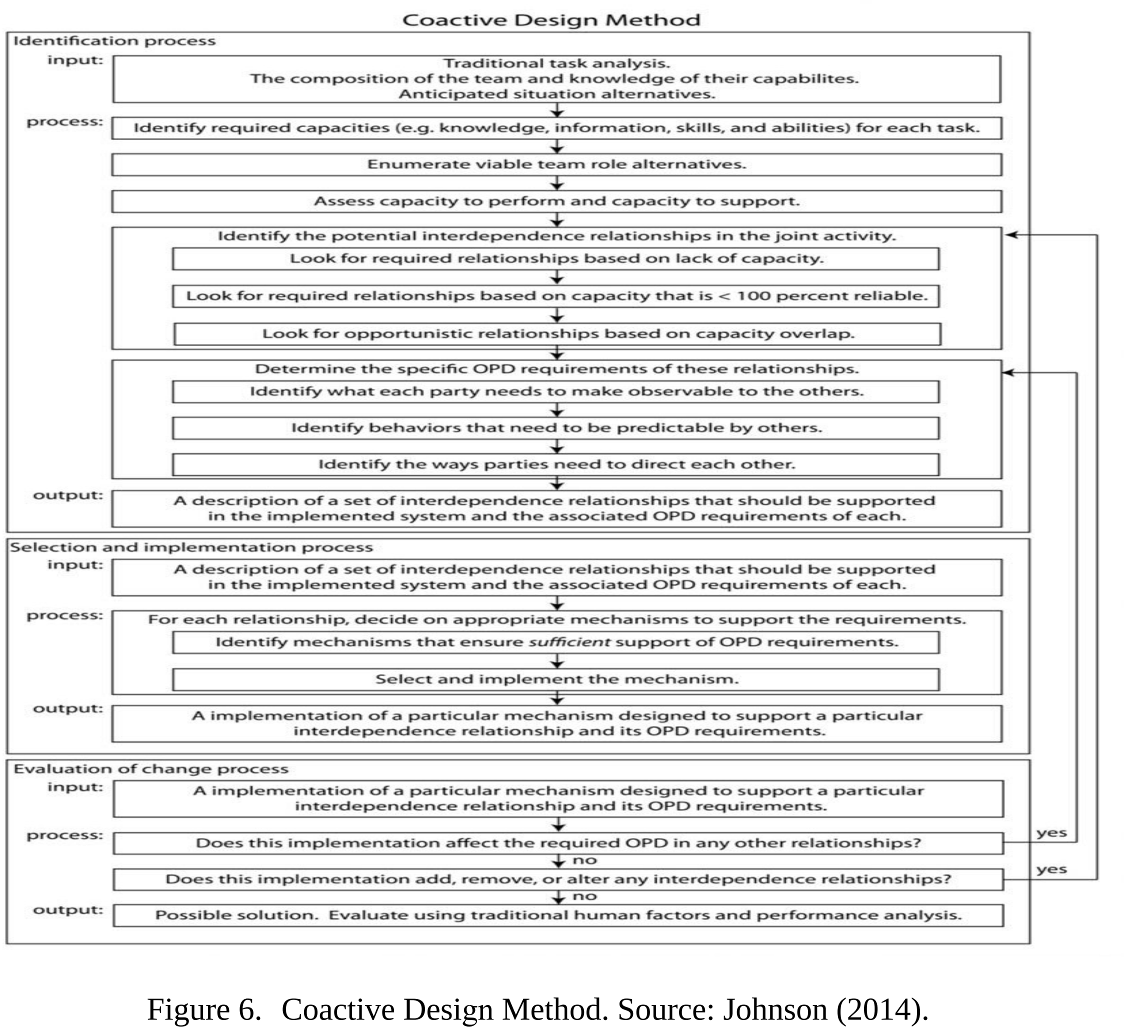

Figure 6. Coactive Design Method. Source: Johnson (2014).

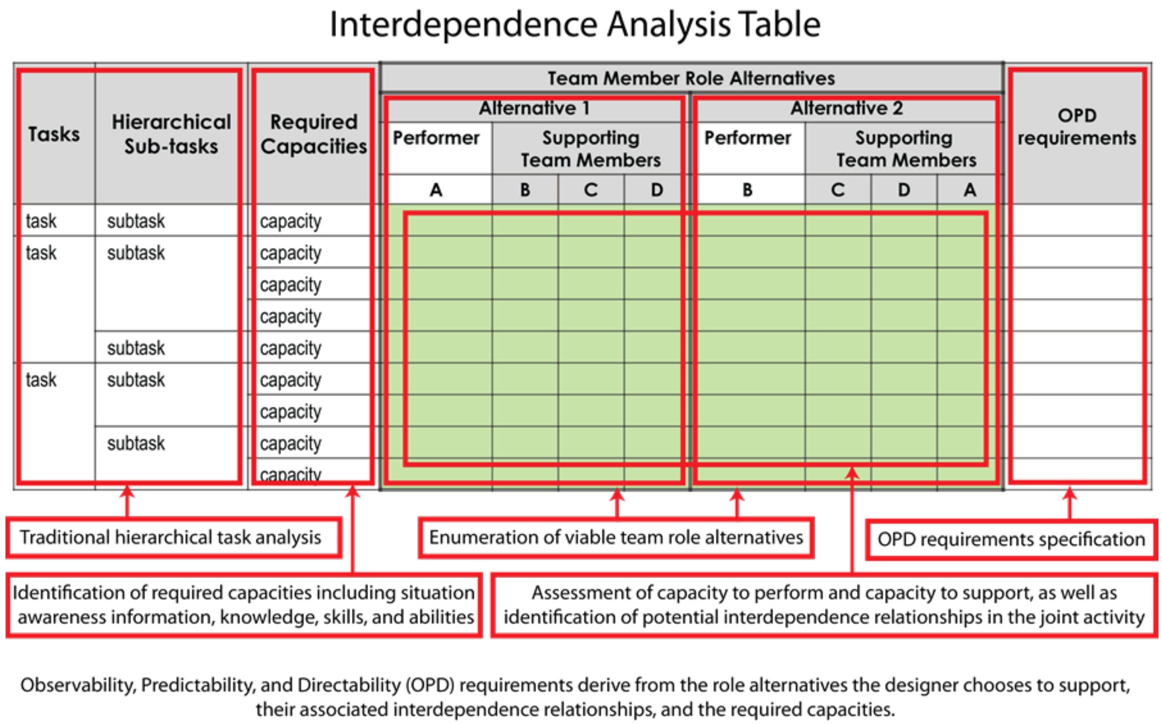

Figure 7. Interdependence Analysis Table. Source: Johnson (2014).

In the design phase of the modeling process, considerable effort was taken to be platform-agnostic when speaking of the specific robotic abilities. Modeling was intended to be done as closely as possible to that of the interactions of the human team members. Once human interactions, communication requirements, and actions are modeled the results were then applied to human UGS interactions. This method allowed the researchers to evaluate the aided benefits, or drawbacks, of each team member.

B. ASSUMPTIONS

Assumptions were made as to the capabilities of the UGS and current functioning capacities for robotic systems. These assumptions were used in the evaluation of the UGS' abilities to perform tasks, sub-tasks, and capacities. Since we are considering future systems, we did not want to limit our analysis to only what is currently available. The main goal is to understand that if such capabilities were available, how would it change the design requirements and how might it potentially impact overall system performance. The output of the process revealed areas in which the team would benefit

from man-machine teaming and thus suggest areas to invest further research resources in order to leverage the benefits of teaming.

In our model the baseline for evaluation of performance lies in the all human fire team. It is understood that humans will have difficulty in completing tasks with 100% success. For our research, we utilized a baseline for a fire team that overcomes these inadequacies with experience and training. For example, a Marine may have trouble staying in formation with correct dispersion and position but will learn to overcome this issue throughout his or her time in the unit. If the goal is to improve the overall human team then the current construct, functioning as intended, must be the benchmark.

C. DEFINITION OF REQUIRED INPUTS

Marine Corps doctrine was the basis for the overall analysis. Utilizing the current doctrine allowed us to develop an overall system picture of fire team interactions during immediate actions. This overall picture is displayed in a decision tree, shown in Figure 8.

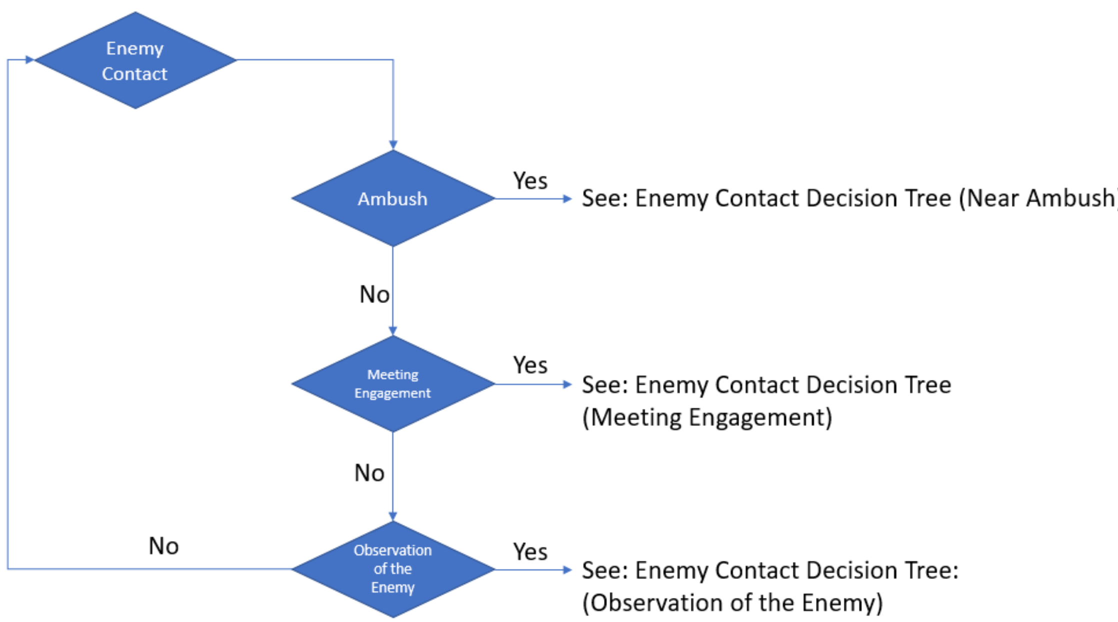

Figure 8. Enemy Contact Decision Tree

At each node in the enemy contact decision tree, an interdependence analysis was completed to evaluate the interactions of the man and unmanned team members. Interdependence analysis begins by considering the required tasks, sub-tasks, and capacities required to complete each sub-task. Instead of only considering the robot and a human, we specifically distinguish the team leader from the rest of the team. This is because information or actions originating from the team leader produce different interactions than those of a team member. As such, we considered three teaming alternatives consisting of a robot, a team leader, and a number of fire team members. Figure 9 shows the three permutations of these options with each potentially being the performer. This allows the analysis to consider, for example, what is different if the robot sees the enemy first versus if the team leader sees the enemy first, versus if a team member sees the enemy first. Each of these alternatives produce different communication pathways and thus different human-machine behavior.

Starting with Marine Corps doctrine the fire team concept and the interactions between its members was inspected breaking down each action into its most elemental tasks and communication requirements.

Task	Required Capacities	Team Member Role Alternatives									OPD Requirements
		Alternative 1			Alternative 2			Alternative 3			
		Performer	Team Members		Performer	Team Members		Performer	Team Members		
		Robot	Team Leader	Marine	Marine	Team Leader	Robot	Team Leader	Marine	Robot	
Task	Capacity 1										
	Capacity 2										
	Capacity 3										

Figure 9. Example IA Table

1. Color Coding

Observability, Directability, and Predictability (OPD) requirements are the outcomes of the research process. These items allow the programmers to design the correct hardware and software to enable the system to work as intended. The required interactions garnered from this analysis will also highlight areas of difficulty thereby indicating areas that will require additional resources to develop.

D. CONCLUSION

This chapter began with discussion of the MCWL mission and the current UTACC concept. Doctrine guided the development of a model for fire team interactions. This model allowed for the breakdown of the processes within the team for further detailed analysis. Coactive design was recommended for implementation by previous researchers and was adapted, with oversight from its author, to fit the current UTACC model of employment. Example tables were depicted for clarification and one completed table shown. The next chapter will explore the results of this implementation.

IV. UTACC COACTIVE DESIGN RESULTS

Chapter three defined how coactive design and Interdependence Analysis are used to determine doctrine based capabilities and associated observability, predictability, and directibility requirements. This chapter provides the results from that application to the UTACC system when considering actions required for the Contact with the Enemy Immediate Action Drill.

The work flow was modeled from the Marine Corps doctrinal responses to enemy contact as illustrated and outlined in Marine Corps Warfighting Publication (MCWP) 3-11.3 *Scouting and Patrolling*. Marine Corps doctrine describes three conditions that satisfy any given situation as enemy contact: 1) Observation of the enemy, 2) meeting engagement, and 3) ambush. We created Interdependence Analysis (IA) tables and decision trees depicting how the man unmanned team (MUM-T) would react.

Due to the size of the IA tables, we have separated them to allow for discussion in this following format. Depending on the contact type classification, several IA tables have been subdivided into multiple sections for ease of presentation. These divisions incrementally step through the process used to create the IA tables. This style of presentation will aid future UTACC research that employs coactive design and Interdependence Analysis and help them understand the author's perspective. The resultant IA tables possess observability, predictability, and directability (OPD) requirements.

For the purpose of this analysis, we utilized the construct of a Marine Corps four-man fire team on patrol, independent of higher associations to squad and platoon level actions. Using the fire team model, and guidance from the Marine Corps Warfighting Laboratory (MCWL), the teaming construct consisted of one robot member and three human members. In line with current design efforts, the robot is representative of the Automatic Rifleman.

According to MCWP 3-11.3, contact with the enemy is broken into three different categories: observation of the enemy, meeting engagement, and ambush. To classify contact with the enemy into one of the three categories we developed standard definitions for each category based upon Marine Corps Doctrine. Observation of the enemy as defined "may be visual, in which the patrol sights the enemy but is not itself detected" (USMC, 2000, p. 11-6). A meeting engagement is defined as "a combat action that occurs when a moving force, incompletely deployed for battle, engages an enemy at an unexpected time and place. It is an accidental meeting where neither the enemy nor the patrol expect contact and are not specifically prepared to deal with it" (USMC, 2000, p. 11-7). An ambush is defined as "a surprise attack from a concealed position" (USMC, 2000, p. 11-7). Analysis begins with a patrol encountering enemy forces but not a determination of which classification the contact falls into. To cue one of the three contact classifications, an initial assessment of the situation needs to occur by one or multiple members of the fire team.

A. CONTACT WITH THE ENEMY: DECISION TREE

To better understand the overall process of Immediate Action Drills in response to enemy contact, we created a decision tree illustrating how the fire team responds in interaction with the enemy (see Figure 10). In our depiction of the decision tree, decision points are represented by diamonds and actions are represented by ovals.

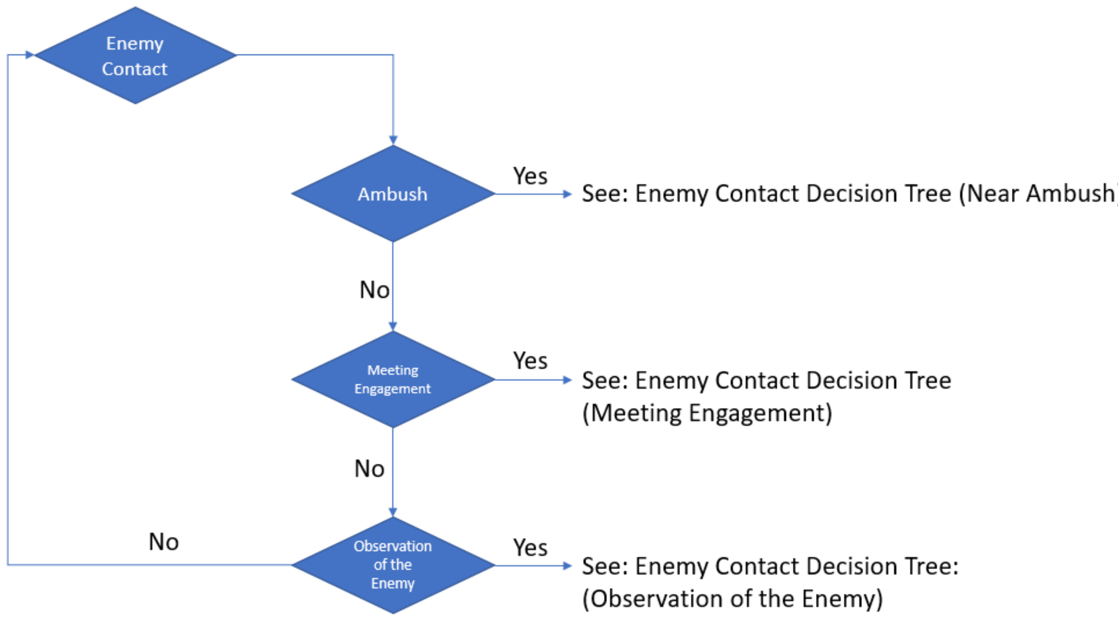

Figure 10. Enemy Contact Decision Tree

Marine Corps Warfighting Publication 3-11.3 states that the immediate action drills begin upon contact with the enemy (USMC, 2000). As the situation develops each team member begins a process to decide (represented by diamonds in the figures) the next appropriate course of action. If the initial decision process cannot confirm that the current situation is enemy contact, then the team continues to search for enemy contact. When enemy contact is confirmed, it is evaluated against an ambush scenario first because it is the most dangerous for the fire team. If enemy ambush criteria are not met, then the information is validated against meeting engagement criteria followed by observation of the enemy. If none of the criteria are met then the situation is not enemy contact and the team continues monitoring for enemy contact.

1. Ambush

a. Near/Far Ambush

When the ambush criteria are met, another decision process begins so as to clarify the type of ambush, since doctrine directs separate actions based upon the ambush type. The following decision tree dictates the immediate action responses for a *near/far*

ambush (see Figure 11.). For a *near ambush* (enemy < 50 meters), which is described as "the killing zone is under very heavy, highly concentrated, close range fires" (USMC, 2000, p. 11-9), the doctrinal action is *immediate assault* toward the enemy ambush position followed by occupation of that position. Constraints upon time and decision space require a more reflex type assault reaction and no time is provided for another decision cycle. When the fire team has occupied the enemy ambush position, there are two options for further action. The fire team leader makes the decision to *break contact* or continue the assault.

If the situation does not classify as *near ambush* it is automatically classified as a *far ambush*. For *far ambush* (enemy > 50 meters), doctrine dictates that the fire team returns fire and seeks cover. Once under cover, the fire team leader will make the decision to continue the assault against the ambush force or *break contact*. Figure 11 depicts the process.

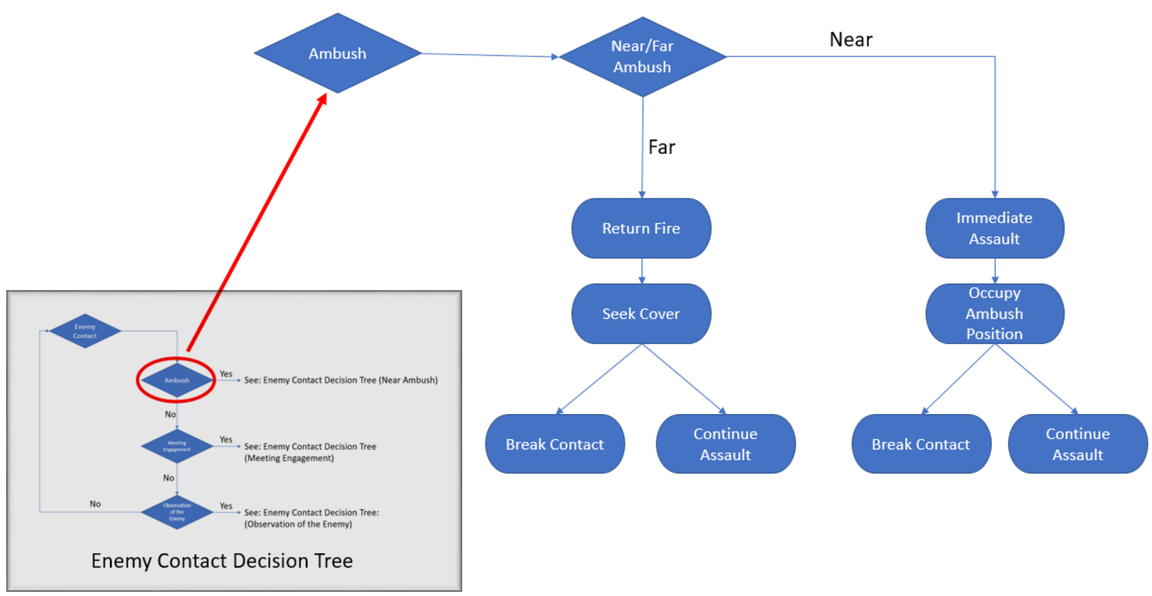

Figure 11. Enemy Contact Decision Tree (Near/Far Ambush)

2. Meeting Engagement

If the initial enemy contact decision process invalidates an ambush scenario, it is then checked against the *meeting engagement* scenario. A *meeting engagement* is an "accidental meeting where neither the enemy nor the patrol expects contact" (USMC, 2000, p. 11-7). If meeting engagement criteria have been met, the fire team leader determines the next course of action (see Figure 12). The options available are to *initiate offensive action* against the enemy force, *initiate defensive action*, or *break contact*.

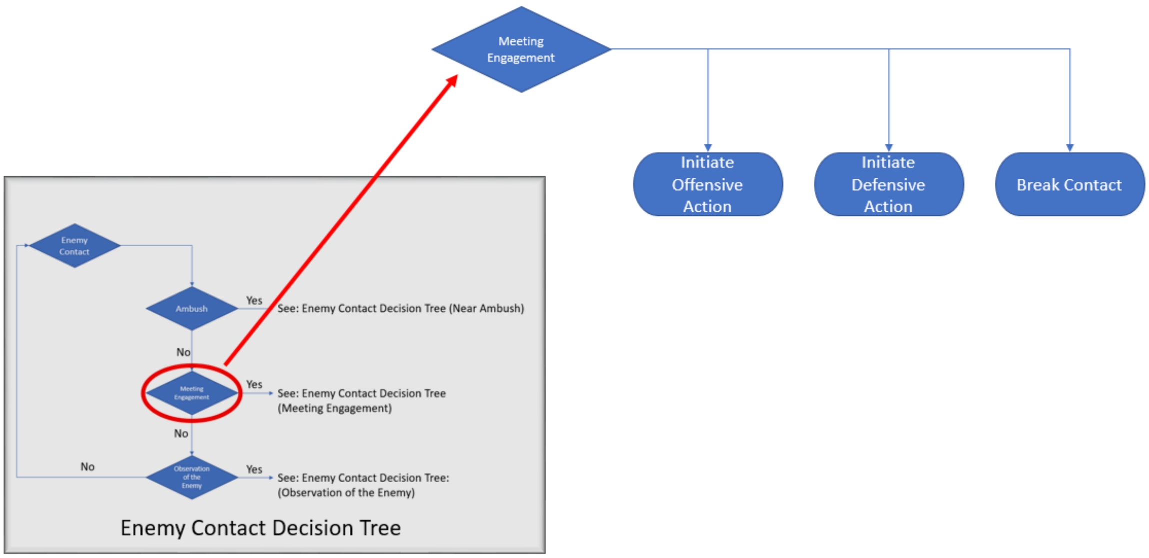

Figure 12. Enemy Contact Decision Tree (Meeting Engagement)

3. Observation of the Enemy

Observation of the enemy is defined as "the patrol sights the enemy but is not itself detected" (USMC, 2000, p. 11-6). When criteria for *observation of the enemy* have been met, the fire team leader decides the team's most prudent next course of action. The two possible actions are to initiate or avoid contact with the enemy (see Figure 13). The action that is chosen will be influenced by the scope of the fire team's mission or by other information relevant to the situation.

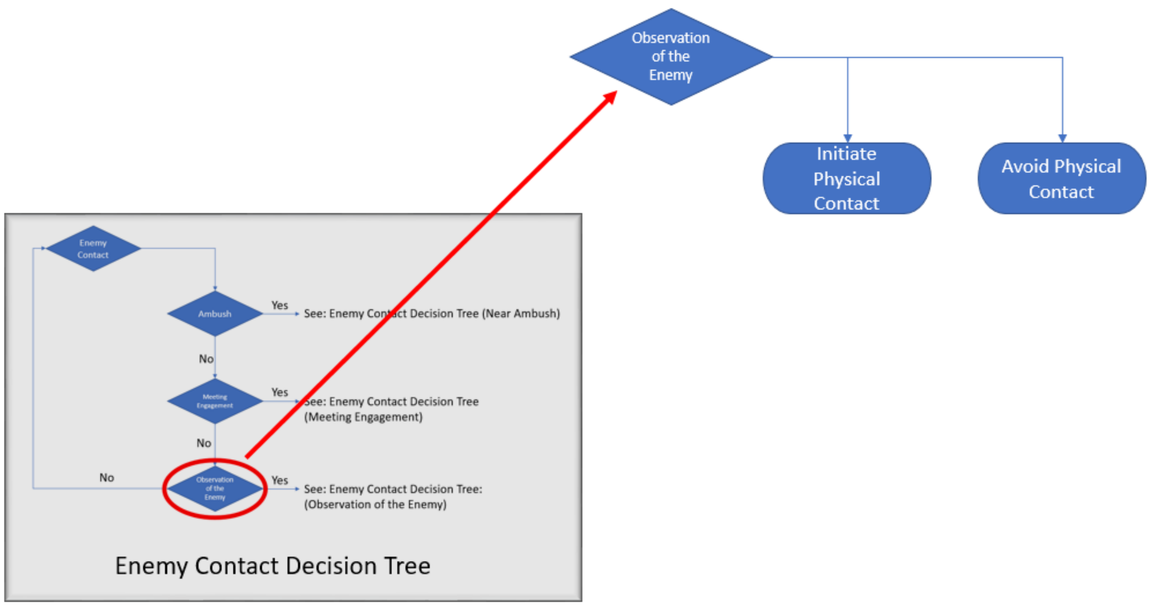

Figure 13. Enemy Contact Decision Tree (Observation of the Enemy)

B. CONTACT WITH THE ENEMY DECISION IA TABLES

1. Initial Contact with the Enemy Decision

To correctly identify the enemy during a patrol, sensory information about the environment needs to be gathered by individual team members. The sub-task of sense is broken down into the following capacities, hear, see, smell, touch, and other sensory input. The next step in the process involves the ability of the individual Marine to take those sensory inputs and match the information to validated enemy identification criteria. The sub-task of recognize is broken down into capacities of awareness of (friendly) team member locations, signal correlation, physical correlation, and auditory correlation. For example, an auditory correlation would be hearing a gunshot and making the association to enemy presence. The final step in the decision process is to use the previously correlated information to reach a decision. The critical component to the decide task is to match all the information collected to determine if the situation qualifies as enemy contact. Figure 14 depicts the IA table for an initial enemy contact determination.

This is not the only decision that is formed by a sense, recognize, and decide set of tasks. In fact, all of the following decision points presented sue the same format, and it is likely true for most immediate actions. The details, though, for each specific decision, will vary. It is crucial for the developer to understand these nuances for UTACC to be a success. For instance, in sensing, it is hypothesized that robots may possess better auditory or low light level sensing. On the other hand, it is likely that recognizing the enemy may be inherently easier for a human. As mentioned before, immediate actions leave little time to help robots recognize or decide, complicating the developers challenges.

Task	Sub-Tasks	Required Capacities	Team Member Role Alternatives									OPD Requirements
			Alternative 1			Alternative 2			Alternative 3			
			Performer	Team Members		Performer	Team Members		Performer	Team Members		
			Robot	Team Leader	Marine	Marine	Team Leader	Robot	Team Leader	Marine	Robot	
Decide (Enemy Contact)	Sense*	Hear										O: None. P: Human team members predict the robot will inform team about anomalies. D: Robot directs humans to direction of anomalies.
		See										O: None. P: Human team members predict the robot will inform team about anomalies. D: Robot directs humans to direction of anomalies.
		Smell**										O: None. P: Human team members predict the robot will inform team about anomalies. D: Robot directs humans to direction of anomalies.
		Touch**										O: None. P: Human team members predict the robot will inform team about anomalies. D: Robot directs humans to direction of anomalies.
		Other Sensors***										O: None. P: Human team members predict the robot will inform team about anomalies. D: Robot directs humans to direction of anomalies.
	Recognize	Separate Possible Enemy from Friendly****										O: Team members observe teammate positioning. P: Team members communicate possible enemy locations. D: Team members query for validation of enemy contact.
		Signal Correlation (Light, wireless, non-visible) To Identify Situation										O: All team members observe performer cue on possible enemy target (rifle aim). P: Team members predict other members will communicate possible enemy. D: Team members query for validation of contact.
		Physical Correlation (Gesture, posture, action) To Identify Situation										O: All team members observe performer cue on possible enemy target (rifle aim). P: Team members predict other members will communicate possible enemy. D: Team members query for validation of contact.
		Auditory Correlation (voice, gunfire, etc.) To Identify Situation										O: All team members observe performer cue on possible enemy target (rifle aim). P: Team members predict other members will communicate possible enemy. D: Team members query for validation of contact.

*All sensory input is for indications of the enemy

**Assume that robot has sensors capable of detecting odor and tactile inputs (vibration, etc.)

*** Robot is equip with other sensors such as night vision, thermal, or other sensors outside of human anatomy.

**** Assumed pre-established method of identifying team member locations (GPS, RFID, etc.)

Figure 14. Interdependence Analysis (Decide Enemy Contact)

The OPD requirements drawn from the *sense* portion of the IA table are concerned with each member's ability to gather information through different senses. All members have the capacity to hear the presence of the enemy, however, the inclusion of a robot in the fire team could assist the human members because the machine may have a wider range of hearing ability or more sensitive equipment. The same determination goes for the capacity to see the enemy: the robot may have the ability to visually identify the enemy prior to the humans in the team. The capacities to smell and touch are not critical senses to use in the scope of contact with the enemy immediate actions, and are not discussed in Marine Corps doctrine as useful faculties to detect the presence of the enemy. However, technological advancements could permit a robotic platform to exploit these sensory avenues in ways people cannot. For example, vibration sensors on robots could be far more sensitive than human capabilities to detect vehicles approaching. Other sensors are those that the machine could have that humans do not, which could add to the overall sensing ability of the entire fire team. For instance, infrared sensors as part of the robot's sensor suite could detect heat signatures of human beings or vehicles that the Marines cannot see.

The OPD requirements drawn from the *recognize* portion of the IA table addresses each member's ability to correlate information to pre-shared knowledge, based upon the sensory input gathered in the previous section. All members have the capacity to know the location of each (friendly) team member and have the ability, in the supporting role, to assist the performer. An interdependent relationship exists in the ability of the team members to assist each other in identifying their location via pre-established communication methods. Correlation of signal, physical, and auditory inputs to pre-shared knowledge also exhibits a possibility for interdependence in that team members can assist one another in validation once an initial correlation has been made. Physical correlation and auditory correlation on behalf of the robot, due to current design limitations and time constraints, can be accomplished but with a reliability of less than 100 percent.

a. Ambush Decision

When the enemy contact decision process has confirmed enemy contact, the next step is determining the type of enemy contact. The most dangerous enemy contact situation is an ambush and as such, all information will be evaluated against this criterion first. Figure 15 depicts the Interdependence Analysis for deciding if the enemy contact is an ambush.

Task	Sub-Tasks	Required Capacities	Team Member Role Alternatives									OPD Requirements
			Alternative 1			Alternative 2			Alternative 3			
			Performer	Team Members		Performer	Team Members		Performer	Team Members		
			Robot	Team Leader	Marine	Marine	Team Leader	Robot	Team Leader	Marine	Robot	
Decide (Ambush)	Sense*	Hear										O: None. P: Human team members predict the robot will inform team about anomalies. D: Robot directs humans to direction of anomalies.
		See										O: None. P: Human team members predict the robot will inform team about anomalies. D: Robot directs humans to direction of anomalies.
		Smell**										O: None. P: Human team members predict the robot will inform team about anomalies. D: Robot directs humans to direction of anomalies.
		Touch**										O: None. P: Human team members predict the robot will inform team about anomalies. D: Robot directs humans to direction of anomalies.
		Other Sensors***										O: None. P: Human team members predict the robot will inform team about anomalies. D: Robot directs humans to direction of anomalies.
	Recognize	Recall Doctrinal Ambush Situation										O: None P: None D: None
		Signal Correlation (Light, wireless, non-visible) To Identify Ambush Situation										O: None. P: Team members predict other members will signal ambush indicators. D: None.
		Physical Correlation (Gesture, posture, action) To Identify Ambush Situation										O: None. P: Team members predict other members will signal ambush indicators. D: None.
		Auditory Correlation (voice, gunfire, etc.) To Identify Ambush Situation										O: None. P: Team members predict other members will signal ambush indicators. D: None.

*All sensory input is for indications of the enemy

**Assume that robot has sensors capable of detecting odor and tactile inputs (vibration, etc.)

*** Robot is equip with other sensors such as night vision, thermal, or other sensors outside of human anatomy.

Figure 15. Independence Analysis (Ambush Decision)

The same capacities for deciding if the collected information is enemy contact are valid for determining if the contact situation is an ambush. The critical component of an ambush decision is the time associated to it. In this instance, there is no time to validate or confirm the correlated sensory information. Success is reliant upon the individual to identify an ambush and signal the possibility of an ambush. The OPD requirements for the *sense* portion of the IA table are the same as the enemy contact decision table above. The OPD requirements for the *recognize* portion of the IA table have changed due to the immediacy of the decision. Now none of the team members can assist the performer because of the danger associated with an ambush. The confirmation of an ambush scenario initiates another decision process to determine if the enemy ambush is classified as near or far.

(1) Near/Far Ambush Decision

The first decision process confirmed contact with the enemy, the second process confirmed the contact was classified as an ambush, and the next decision process determines if the ambush is a near ambush. A near ambush is when the enemy ambush position is less than 50 meters from the fire teams' position. A near ambush is more dangerous than a far ambush due to proximity and therefore must be considered first. Figure 16 depicts the near/far ambush decision process.

Task	Sub-Tasks	Required Capacities	Team Member Role Alternatives									OPD Requirements
			Alternative 1			Alternative 2			Alternative 3			
			Performer	Team Members		Performer	Team Members		Performer	Team Members		
			Robot	Team Leader	Marine	Marine	Team Leader	Robot	Team Leader	Marine	Robot	
Decide (Near Ambush)	Sense*	Hear										O: None. P: Human team members predict the robot will inform team about anomalies. D: Robot directs humans to
		See										O: None. P: Human team members predict the robot will inform team about anomalies. D: Robot directs humans to direction of anomalies.
		Smell**										O: None. P: Human team members predict the robot will inform team about anomalies. D: Robot directs humans to direction of anomalies.
		Touch**										O: None. P: Human team members predict the robot will inform team about anomalies. D: Robot directs humans to direction of anomalies.
		Other Sensors***										O: None. P: Human team members predict the robot will inform team about anomalies. D: Robot directs humans to direction of anomalies.
	Recognize	Separate Possible Enemy from Friendly****										O: Team members observe teammate positioning. P: None D: None
		Recall Doctrinal Near Ambush Situation										O: None P: None D: None
		Signal Correlation (Light, wireless, non-visible) To Identify Near Ambush										O: None. P: Team members predict other members will signal ambush indicators. D: None.
		Physical Correlation (Gesture, posture, action) To Identify Near Ambush										O: None. P: Team members predict other members will signal ambush indicators. D: None.
		Auditory Correlation (voice, gunfire, etc.) To Identify Near Ambush										O: None. P: Team members predict other members will signal ambush indicators. D: None.

*All sensory input is for indications of the enemy

**Assume that robot has sensors capable of detecting odor and tactile inputs (vibration, etc.)

*** Robot is equip with other sensors such as night vision, thermal, or other sensors outside of human anatomy.

**** Assumed pre-established method of identifying team member locations (GPS, RFID, etc.)

Figure 16. Near/Far Ambush Decision

The OPD requirements for a near/far ambush decision are similar to an ambush situation. The difference is in the recognition portion of the table where the recognition of the specific instance of a n*ear ambush* validates the near ambush decision. That decision allows for follow on actions, specific to *near ambush* immediate actions, to be executed. For a *near ambush* the available immediate action responses are *immediate assault* (see Figure 19) followed by *occupy the enemy position*. After the fire team has occupied the enemy position, the available actions are to *break contact* (see Figure 23 and Figure 24) or *continue assault*. Continuing an assault has the same capacities associated to it as an *immediate assault* (see Figure 19) and the interdependence analysis is treated the same. If the decision process invalidates near ambush criteria, the situation qualifies as a far ambush scenario and initiates far ambush immediate actions. For a *far ambush*, the immediate actions are to *return fire* (see Figure 22) and then *seek cover* (see Figure 25). After the team has occupied cover, the fire team leader specifies whether the team will *break contact* (see Figure 23 and Figure 24) or *continue assault*.

b. Meeting Engagement Decision

The second most dangerous enemy contact situation for a Marine Corps fire team is entering a *meeting engagement* with the enemy. After the enemy contact decision process is complete, and the ambush decision process invalidates an ambush situation, a decision process initiates to determine if the current situation meets the *meeting engagement* criteria. Figure 17 depicts the decision process for determining if the situation qualifies as a *meeting* engagement.

Task	Sub-Tasks	Required Capacities	Team Member Role Alternatives									OPD Requirements
			Alternative 1			Alternative 2			Alternative 3			
			Performer	Team Members		Performer	Team Members		Performer	Team Members		
			Robot	Team Leader	Marine	Marine	Team Leader	Robot	Team Leader	Marine	Robot	
Decide (Meeting Engagement)	Sense*	Hear										O: None. P: Human team members predict the robot will inform team about anomalies. D: Robot directs humans to direction of anomalies.
		See										O: None. P: Human team members predict the robot will inform team about anomalies. D: Robot directs humans to direction of anomalies.
		Smell**										O: None. P: Human team members predict the robot will inform team about anomalies. D: Robot directs humans to direction of anomalies.
		Touch**										O: None. P: Human team members predict the robot will inform team about anomalies. D: Robot directs humans to direction of anomalies.
		Other Sensors***										O: None. P: Human team members predict the robot will inform team about anomalies. D: Robot directs humans to direction of anomalies.
	Recognize	Separate Possible Enemy from Friendly****										O: Team members observe teammate positioning. P: Team members communicate possible enemy locations. D: Team members query for validation of enemy contact.
		Recall Doctrinal Meeting Engagement Situation										O: None P: None D: None
		Signal Correlation (Light, wireless, non-visible) To Identify Meeting Engagement Situation										O: All team members observe performer cue on enemy target (rifle aim). P: Team members communicate possible meeting engagement. D: Team members query for validation of meeting engagement.
		Physical Correlation (Gesture, posture, action) To Identify Meeting Engagement Situation										O: All team members observe performer cue on enemy target (rifle aim). P: Team members communicate possible meeting engagement. D: Team members query for validation of meeting engagement.
		Auditory Correlation (voice, gunfire, etc.) To Identify Meeting Engagement Situation										O: All team members observe performer cue on enemy target (rifle aim). P: Team members communicate possible meeting engagement. D: Team members query for validation of meeting engagement.

*All sensory input is for indications of the enemy

**Assume that robot has sensors capable of detecting odor and tactile inputs (vibration, etc.)

*** Robot is equip with other sensors such as night vision, thermal, or other sensors outside of human anatomy.

**** Assumed pre-established method of identifying team member locations (GPS, RFID, etc.)

Figure 17. Meeting Engagement Decision

In a *meeting engagement*, the immediate threat of surprise enemy fire as in an ambush scenario is removed. Therefore, there is more time to decide and further to validate the situation. This time allows for the assistance of other team members. The result of this decision cycle determines the immediate action responses for *meeting engagement* contact with the enemy. Marine Corps doctrine dictates that there are three available responses for a meeting engagement with the enemy, *initiate offensive action*, *initiate defensive action*, and *break contact*. If the fire team is going to *initiate offensive action*, it is the same as an *immediate assault* task (see Figure 19) for ambush scenarios. When the fire team *initiates a defensive action* (see Figure 19), it is with the intention of attacking the enemy until the enemy chooses to break contact. Doctrine defines defensive action, "the assault is stopped if the enemy withdrawals and contact is broken quickly. If the enemy stands fast, the assault is carried through the enemy positions and movement is continued until contact is broken" (USMC, 2000, 11-8). For the purpose of our analysis, *initiate offensive action*, *initiate defensive action*, and *immediate assault* have the same IA table (see Figure 19). When the fire team decides to *break contact* (see Figure 23 and Figure 24), it is the same action as breaking contact in a *far ambush* scenario. The IA Table and OPD requirements do not change except when breaking contact from a meeting engagement, the immediate action drill does not require firing upon the enemy. While breaking contact, engaging the enemy with direct fire weapons is only utilized if it is unavoidable.

There are small nuances in the design process due to danger and time constraints. In cases where the enemy is farther (> 50 meters) this distance allows for more decision space as well as ability to position team members. For example, the *near ambush* immediate action drill is meant to be a reflex action with no communication or direction while the meeting engagement drill leaves options to be directed by the team leader.

c. Observation of the Enemy Decision

The final enemy contact situation that a fire team can enter is *observation of the enemy*. If the current situation does not meet criteria for a meeting engagement, a decision process is started for determining if the situation meets *observation of the enemy*

criteria. In an *observation of the enemy* scenario, the Marine fire team has identified and located an enemy force but the enemy has not yet seen or discovered the fire team. This scenario provides the maximum amount of time for a decision due to the lack of immediate danger and the element of surprise on behalf of the fire team. Figure 18 depicts the decision process for *observation of the enemy*.

Task	Sub-Tasks	Required Capacities	Team Member Role Alternatives									OPD Requirements
			Alternative 1			Alternative 2			Alternative 3			
			Performer	Team Members		Performer	Team Members		Performer	Team Members		
			Robot	Team Leader	Marine	Marine	Team Leader	Robot	Team Leader	Marine	Robot	
Decide (Observation of the enemy)	Sense*	Hear										O: None P: The robot will inform team about anomalies D: Robot needs to inform human team members
		See										O: None P: The robot will inform team about anomalies D: Robot needs to inform human team members
		Smell**										O: None P: The robot will inform team about anomalies D: Robot needs to inform human team members
		Touch**										O: None P: The robot will inform team about anomalies D: Robot needs to inform human team members
		Other Sensors***										O: None P: The robot will inform team about anomalies D: Robot needs to inform human team members
	Recognize	Separate Possible Enemy from Friendly****										O: Team members observe teammate positioning. P: None D: None
		Signal Correlation (Light, wireless, non-visible) To Identify Situation										O: All team members observe performer cue on enemy target (rifle aim). P: Team members predict other members will communicate possible observation of the enemy. D: Team members query for validation of observation of enemy.
		Physical Correlation (Gesture, posture, action) To Identify Situation										O: All team members observe performer cue on enemy target (rifle aim). P: Team members predict other members will communicate possible observation of the enemy. D: Team members query for validation of observation of enemy.
		Auditory Correlation (voice, gunfire, etc.) To Identify Situation										O: All team members observe performer cue on enemy target (rifle aim). P: Team members predict other members will communicate possible observation of the enemy. D: Team members query for validation of observation of enemy.

*All sensory input is for indications of the enemy

**Assume that robot has sensors capable of detecting odor and tactile inputs (vibration, etc.)

*** Robot is equip with other sensors such as night vision, thermal, or other sensors outside of human anatomy.

**** Assumed pre-established method of identifying team member locations (GPS, RFID, etc.)

Figure 18. Observation of the Enemy Decision

The *Observation of the enemy* decision process affords the fire team the maximum ability for teaming out of all contact scenarios. This is because with *observation of the enemy* the enemy is unaware of the fire team's presence. This is the last decision process in determining enemy contact. Upon entering this scenario, Marine Corps doctrine dictates two possible responses: *initiate physical contact* or *avoid physical contact*. If the fire team is going to *initiate physical contact* with the enemy, the interdependence analysis is viewed the same as an *immediate assault*. Initiating the engagement is typically done by the fire team setting up a hasty ambush or a planned fire and maneuver assault. When the fire team has decided to avoid contact with the enemy, the interdependence analysis is viewed the same as breaking contact with the enemy. In breaking contact, the fire team can choose to avoid contact and/or observation by the enemy.

C. CONTACT WITH THE ENEMY ACTION IA TABLES

1. Immediate Assault

The most dangerous enemy contact situation for a fire team is an enemy ambush. If determined that the ambush is a *near ambush* the next course of action is *immediate assault* and occupation of the enemy position. Figure 19 depicts the Interdependence Analysis of the actions of an *immediate assault*.

Task	Required Capacities	Team Member Role Alternatives									OPD Requirements
		Alternative 1			Alternative 2			Alternative 3			
		Performer	Team Members		Performer	Team Members		Performer	Team Members		
		Robot	Team Leader	Marine	Marine	Team Leader	Robot	Team Leader	Marine	Robot	
Immediate Assault	Identify Direction of incoming fire*										O: Robot observes human directional signals. Humans observe robot directional signals. P: Team members predict other members to signal direction of incoming fire if known. D: Robot can direct humans onto targets.
	Communicate (contact, and direction)**										O: None. P: Team members predict other members will communicate known contact information and will repeat/relay contact information. D: None
	Return Fire										O: Team members observe other members firing in direction of enemy. P: Team members will only fire on enemy locations. D: Team members accept commands to modify returning fire (cease, shift, increase rate).
	Position to On Line formation										O: Robot observes human team members moving to formation positions. Humans observe robot moving into correct position. P: Team members will assume correct formation position D: Team leader directs position corrections.
	Buddy Rush										See Buddy Rush IA Table

* Potential for team improvement via interdependence (tracer rounds, communication suites, etc.).
** There is a pre-established successful communication method between all members of the fire team

Figure 19. Interdependence Analysis (Immediate Assault)

The task of *immediate assault* consists of five capacities. The two most important capacities are identifying the direction of the enemy and communicating with the other team members in order to “close with and destroy the enemy by fire and maneuver” (USMC, 2002, 1-1). In identifying the direction of enemy fire, the IA table shows possible interdependence between team members by the supporting members in alerting

the team to the direction of the enemy. They increase reliability in accomplishing this capacity. It is assumed that the robot will be able to determine direction with more accuracy than its human counterparts. Through this relationship the robot can assist the human team members, using better sensing technology or other physical means (tracer rounds), to put accurate fire on target.

a. Buddy Rush

The capacities *buddy rush* and *return fire*, are viewed as separate tasks and are broken down into further IA tables. Figure 20 depicts analysis conducted for *buddy rush*.

Task	Required Capacities	Team Member Role Alternatives									OPD Requirements
		Alternative 1			Alternative 2			Alternative 3			
		Performer	Team Members		Performer	Team Members		Performer	Team Members		
		Robot	Team Leader	Marine	Marine	Team Leader	Robot	Team Leader	Marine	Robot	
Buddy Rush	Know the location of your buddy										O: Team members observe location of their buddy. P: Team members predict buddy moves in appropriate distance and correct direction. D: None
	Communicate (Firing, not firing)*										O: None P: Buddy will communicate when firing or moving. D: None
	Move										See Move IA Table
	Fire										See Return Fire IA Table

* There is a pre-established successful communication method between all members of the fire team

Figure 20. Interdependence Analysis (Buddy Rush)

The task of *buddy rush* has four capacities that can be summarized as "shoot, move, and communicate (a standard Marine proverb)." The OPD requirements derived from this analysis results in that all members can accomplish these actions but none of the supporting members can assist the performer. These actions are truly independent

actions that must be accomplished by each individual team member in order to accomplish the task. From a development perspective, the robot must be built to accomplish these capabilities by itself, when triggered.

(1) Move

Within the task of *buddy rush* (see Figure 20) is the capacity of *move*, indicating the ability for the performer to achieve a certain destination. Movement of any kind is a difficult procedure and was evaluated further using interdependence analysis. Figure 21 depicts the analysis conducted for the task of move.

Task	Required Capacities	Team Member Role Alternatives									OPD Requirements
		Alternative 1			Alternative 2			Alternative 3			
		Performer	Team Members		Performer	Team Members		Performer	Team Members		
		Robot	Team Leader	Marine	Marine	Team Leader	Robot	Team Leader	Marine	Robot	
Move	Identify direction of movement										O: Team members must observe current location of other members. P: Humans must predict robot's path of movement. Robot must predict human's movement. D: None.
	Identify path of movement to narrow focus										O: None. P: None. D: None.
	Observe obstacles in planned path										O: None. P: None. D: None.
	Avoid obstacles in planned path*										O: None. P: None. D: None.

** Obstacles must be avoided in a means that minimizes expose of the robot or team members to enemy fire or observatio

** Each Team member is performing this action. It is assumed that no team member can assist another to avoid obstacles.

Figure 21. Interdependence Analysis (Move)

The *move* task is broken down into four capacities. The process is continuous until the action is completed. The OPD requirements are concerned with identifying the intended destination and taking the necessary steps to reach that objective. In the *identifying the direction of movement* capacity, the IA table identifies potential for interdependence because the supporting members can increase reliability in accomplishing this task. Communication between team members facilitates the team moving in the correct direction. All the other capacities are independent actions where no support from the other team members can be provided. The capacity of *observing obstacles* is difficult for the robot due to increased potential for false positives and false negatives.

b. Return Fire

Only when a team member has completed the task of *return fire* can they move on to the next task of *seek cover*. *Return fire* is a complex capacity within many different tasks conducted by a fire team. Interdependence Analysis of *return fire* as a task can provide greater insight into potential interdependencies and support activities. Figure 22 depicts the interdependence analysis and OPD requirements for the task of *return fire*.

Task	Required Capacities	Team Member Role Alternatives									OPD Requirements
		Alternative 1			Alternative 2			Alternative 3			
		Performer	Team Members		Performer	Team Members		Performer	Team Members		
		Robot	Team Leader	Marine	Marine	Team Leader	Robot	Team Leader	Marine	Robot	
Return Fire	Identify Direction of Incoming Fire to locate targets										O: Team members orient weapon to direction of enemy positions P: Team members fire on enemy locations. D: Team members accept commands to modify returning fire (cease, shift, increase rate).
	Range to Enemy										O: None. P: Team members will communicate enemy range. D: Team member will adjust fire to communicated ranges.
	Location of Friendly Forces										O: Team members observe each other's positions P: Team members will not fire upon friendly positions D: None.
	Weapon Status										O: Human members can observe robot changing rate of fire. P: Team members will communicate weapon status when appropriate (out of action etc.) D: Robot directs humans to increase/decrease rates of fire and remaining ammo counts.

Figure 22. Interdependence Analysis (Return Fire)

The task of *return fire* has four capacities. The ability to identify the direction of incoming fire demonstrates the same interdependence as the *immediate assault* task. Identifying range to the enemy can be accomplished by all team members. A potential for interdependence lies with the robot providing more precise information to the human members of the team thereby increasing efficiency. The robot has a sensor suite that would be able to identify range more precisely than the human team members in an incoming fire situation. Humans under a time constraint will be less precise in identifying range to the enemy than the robot would. The capacity of weapon status revolves around the performer knowing critical information about the weapon system such as weapon effective range (point target, area target) and instant ammunition counts. The robot acting as the performer has a better ability than its human counterparts to monitor this detailed information. Therefore, the robot can provide this information to the human members to more efficiently maximize the combat effectiveness of the fire team. Once the team has occupied the ambush position, the fire team leader decides to continue the assault on the enemy seeking his destruction, or to *break contact* with the enemy.

2. Break Contact

There are two possible methods to *break contact*. The first is breaking contact by *fire and maneuver* and the second is by the clock method. Figure 23 depicts the interdependence analysis of the action *break contact* using *fire and maneuver* and Figure 24 depicts *break contact* using the *clock method*.

a. Fire and Maneuver

To *break contact* by fire and maneuver is to have “one portion of the patrol returns the enemy fire, while another portion moves by bounds away from the enemy. Each portion of the patrol covers the other by fire until contact is broken by all” (USMC, 2000, p. 11-8).

Task	Required Capacities	Team Member Role Alternatives									OPD Requirements
		Alternative 1			Alternative 2			Alternative 3			
		Performer	Team Members		Performer	Team Members		Performer	Team Members		
		Robot	Team Leader	Marine	Marine	Team Leader	Robot	Team Leader	Marine	Robot	
Break Contact (Fire and Maneuver)	Know the location of team members										O: Team members observe location of their buddy. P: Team members predict buddy moves in appropriate distance and correct direction. D: None
	Communicate (Firing & not Firing)										O: None P: Buddy will communicate when firing/moving. D: None
	Move (Away from enemy)										See Move IA Table
	Fire										See Return Fire IA Table

Figure 23. Interdependence Analysis (Break Contact by Fire and Maneuver)

The task of *break contact by fire and maneuver* has the same OPD requirements as *buddy rush*; with the primary difference being the movement is away from the direction of contact to put distance between the fire team and the enemy. Due to time constraints and proximity to danger, these capacities are truly independent actions that cannot be supported by any member of the team.

b. Clock Method

An example of the breaking contact using the clock method is shouting “TEN O’CLOCK – TWO HUNDRED” where the fire team’s direction of motion is twelve o’clock and the team “should move in the direction of ten o’clock for 200 meters” (USMC, 2000, p. 11-8).

Task	Required Capacities	Team Member Role Alternatives									OPD Requirements
		Alternative 1			Alternative 2			Alternative 3			
		Performer	Team Members		Performer	Team Members		Performer	Team Members		
		Robot	Team Leader	Marine	Marine	Team Leader	Robot	Team Leader	Marine	Robot	
Break Contact (Clock System)	Know relative heading (of patrol)*										O: None. P: Team members predict other members are following patrol's heading. D: Team leader directs members to correct heading when off course.
	Identify path along break contact heading										O: None. P: Team members predict others will move in correct direction. D: Team leader directs team members to correct heading.
	Evaluate distance										O: None. P: Team members predict other members communicate intended direction and distance. D: Team members will correct as directed.
	Move										See move IA table

*Individuals heading is not important. The clock system is based upon the relative heading of the entire team

Figure 24. Interdependence Analysis (Break Contact by Clock Method)

The task is broken down into four capacities. The first capacity of *knowing the heading of the patrol* can be accomplished by all members, but the team leader ultimately dictates the direction of the team. The potential for interdependence resides in the team leader providing and communicating the general heading to the rest of the team. The capacity of *identify a path along the indicated direction* is an independent task where none of the supporting team members can assist the performer. The capacity of *evaluate distance* can be accomplished by all members of the team. The robot, due to improved sensors, can more accurately determine the correct distance. The interdependence resides in the robot providing information to the human team members to increase the team's reliability in determining distance. The remaining capacity *move* is performed by all team

members individually. There is no available interdependent relationship for this capacity meaning it is an independent action.

3. Seek Cover

Once it is determined that the current situation is a *far ambush*, immediate action drills commence to provide protection for the fire team. The immediate action drill directs team members to immediately *return fire* followed by *seek cover*. Return fire was discussed earlier (see Figure 22). Figure 25 depicts the Enemy Contact Decision Tree for the immediate action of *seek cover*. Cover is defined as “protection from fire or hostile weapons” (USMC, 2000, p. 4-1).

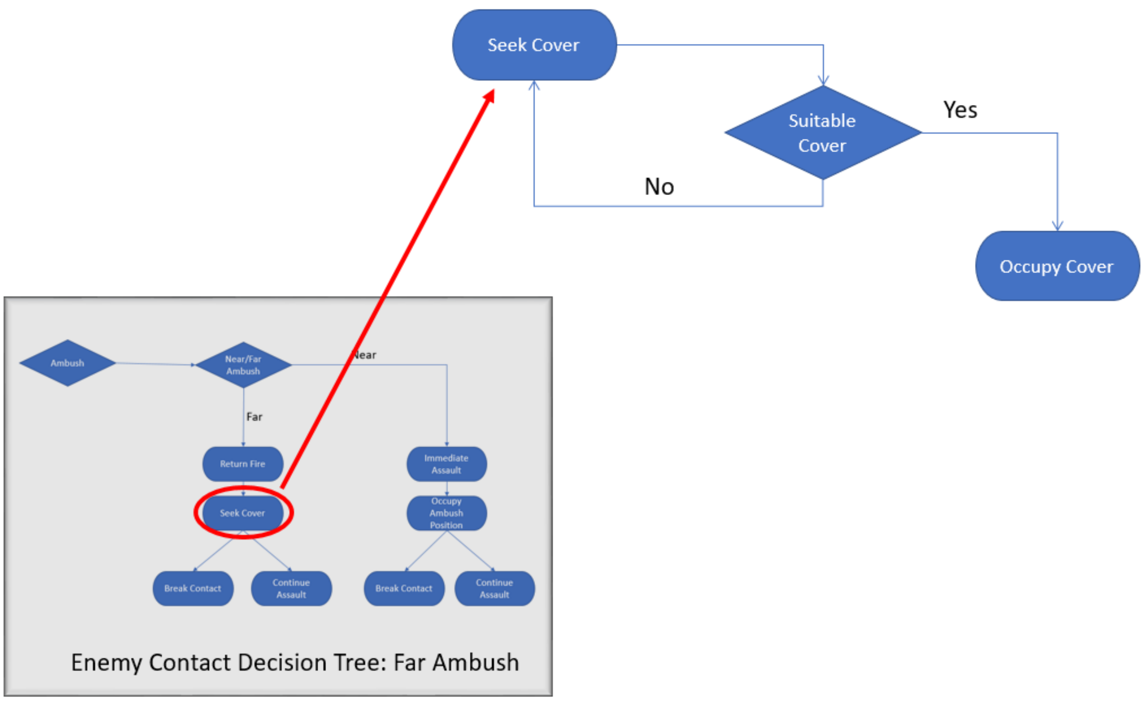

Figure 25. Enemy Contact Decision Tree (Seek Cover)

a. Identify Suitable Cover

Seek cover is a complex action that requires two separate tasks. When seeking cover, a decision process is initiated to evaluate the terrain in the immediate vicinity to select the most suitable cover. After suitable cover has been identified and selected, the fire team member moves to occupy that covered position. Figure 26 depicts the IA table and OPD requirements for identifying suitable cover.

Task	Required Capacities	Team Member Role Alternatives									OPD Requirements
		Alternative 1			Alternative 2			Alternative 3			
		Performer	Team Members		Performer	Team Members		Performer	Team Members		
		Robot	Team Leader	Marine	Marine	Team Leader	Robot	Team Leader	Marine	Robot	
Identify Suitable Cover	Identify Enemy Position										O: Team members observe enemy positions. P: Team members communicate enemy positions. D: Robot directs humans onto enemy position, and vise versa.
	Identify Obstacles between Current Location and Enemy Location										O: None. P: None. D: None.
	Identify Size of Obstacle										O: None. P: None. D: None.
	Identify Composition of Obstacle										O: None. P: None. D: None.

Figure 26. Interdependence Analysis (Identify Suitable Cover)

The task of *identify suitable cover* is composed of four capacities. Identifying obstacles between the team member's current location and the enemy location can be accomplished by all team members. No supporting members can assist the performer because of the time constrained nature of the situation (proximity to danger and time). The identification of obstacles facilitates finding the location of objects that provide sufficient cover. The subsequent capacity of identifying the size of the obstacle is designed to create a prioritized list of suitable cover locations starting from best to worst.

Larger obstacles provide better cover. The final capacity is to identify the material composition of the obstacle providing cover. The human team members accomplish this in a time constrained environment successfully while the robot cannot accomplish this action. It is critical to identify the composition of possible cover locations because varied compositions provide varied levels of protection. For example, a large plant can successfully meet the criteria for suitable cover (size, location, etc.), yet its composition does not provide protection.

b. Occupy Cover

After a suitable cover position has been identified a decision process is initiated to decide whether movement to that location is possible. Figure 27 depicts the IA table and OPD requirements for occupying a cover position.

		Team Member Role Alternatives									
		Alternative 1			Alternative 2			Alternative 3			
		Performer	Team Members		Performer	Team Members		Performer	Team Members		
Task	**Required Capacities**	Robot	Team Leader	Marine	Marine	Team Leader	Robot	Team Leader	Marine	Robot	**OPD Requirements**
Occupy Cover	Identify Lines of Fire to avoid										O: None. P: Team members will avoid lines of fire. D: None.
	Route Planning/Finding to suitable cover location										O: None. P: Team members predict performer takes safest and shortest path. D: None.
	Identify Friendly Trajectory to deconflict with own planned route										O: Team members observe and anticipate each others' routes to cover. P: No two team members will occupy the same cover if possible. D: Team members will accept commands to deconflict destinations.

Figure 27. Interdependence Analysis (Occupy Cover)

The task of *occupy cover* is broken into three capacities. Identifying lines of friendly fire can be accomplished by all team members with less than 100% reliability. This capacity requires the understanding of where shots are initiating from (friendly and enemy) as well as their impact locations. Team members cannot cross lines of fire while transiting to cover locations. The capacity of *route planning/finding* can be accomplished by all members of the fire team. The capacity of identifying the future location of the other team members is difficult for all team members because it involves predicting movements of other team members. Possible interdependence lies with the team members indicating and communicating their intended movement which increases reliability.

D. CHAPTER SUMMARY AND CONCLUSIONS

This chapter presented the results of Immediate Action Drills upon contact with the enemy using the coactive design model. Marine Corps Doctrine drove production of a process flowchart for Immediate Actions for enemy contact. The flowchart documents the human decision process which identified instances where coactive design can be implemented for a man machine integrated fire team. For each instance, an IA table evaluated capacities for performing critical tasks. OPD requirements were derived from the results of the IA tables to influence future design decisions.

This methodology for analysis is beneficial for making predominant design recommendations at an overarching level. Because this is the initial study of coactive design applied to fire team immediate actions, the analysis was kept broad. The analysis process used for the UTACC concept was independent of any specific robotic platform, leaving out the details of modality and form to emphasize design instead of evaluation of a current system. It was applied to the platform within the Marine Corps doctrinal implementation requirements of the robot acting as a member of the four-man fire team and not supplementing or augmenting that foundation. The findings of this analysis will be applied to future design models in order to create a system that can perform all of the stated tasks without increasing cognitive demands on the human team members.

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V. SUMMARIZING RESULTS AND RECOMMENDATIONS FOR FUTURE RESEARCH

A. PROCESS OVERVIEW

Chapter two explained the coactive design model, interdependence analysis, and OPD. Chapter three described our research methodology using coactive design and IA tables to evaluate potential relationships between members of the Marine Corps four-man fire team. Chapter four identified the relationships between human and robotic team members and analyzed the interdependence required to accomplish immediate action drills for enemy contact using MCWP 3-11.3 as guiding documentation.

1. Fire Team Construct

This paper uses the standard Marine Corps four-man fire team construct having the robot fulfill the role of the Automatic Rifleman. The fire team was analyzed independent of adjacent and higher units. Current UTACC concepts drive this research and are directed by MCWL concerning implementation.

2. Doctrine

It is important to remember that all the research and analysis conducted in this paper primarily utilized MCWP 3-11.3 doctrinal responses to enemy contact. Following doctrine allows for a consistent point of departure for analysis. Marine Corps units may develop different, specific standard operating procedures (SOP) to address enemy contact situations, but doctrine is the basis for Marine Corps units and is taught at all entry level schools.

3. Decision Tree

We created a decision tree to identify repetitive actions and model logical linear flow of immediate action drills. The tree begins in identifying the enemy, and continues until all possible actions for immediate action drills are complete. This enables analysis and deconstruction of individual team member's processes throughout each enemy contact event.

4. Interdependence Analysis (IA) Tables

Using Johnson et al.'s (2014) coactive design Interdependence Analysis Tables highlighted relationships between members of the fire team. These are used to draw out possible areas for supporting-supported relationships among team members. Each member has unique skills and talents and only through effective relationships can the team utilize all available abilities to reach its full potential. IA tables are a tool to identify interdependence areas influencing design and future resourcing to develop and capitalize on the identified areas.

B. OBSERVABILITY, PREDICTABILITY, DIRECTABILITY (OPD) REQUIREMENTS

Derived from the analysis of respective IA tables, we identified OPD requirements necessary for accomplishing the various immediate action drill tasks. These requirements provide insight as to the communications processes between team members throughout movements and actions. Once the requirements are identified, resources can be invested to improve weak areas.

1. Results

The analysis revealed repetitive as well as continuous processes. We discovered many decision points that preceded directed actions during enemy contact. These decision points occurred multiple times throughout each process and were crucial to accomplishing all the immediate action drills. Each decision point, at a minimum, contains sense, recognize, and decide tasks. Further, continuous processes that were identified include searching for the enemy, locating friendly forces, searching for cover, and communicating. This information is useful for design purposes, especially creating software. Those simultaneous and ongoing tasks are required in programming to create an effective and efficient team member.

2. Interdependence

Interdependence, as identified in this thesis, includes possible areas where human and robot teaming can occur. Those areas are where using MUM-T can greatly enhance

the capability of the team above pure human fire teams. All interactions and contributions between teammates lead to enhanced OPD in the conduct of immediate action drills.

a. Sense

The analysis results of the sensing task found possibilities for interdependence between team members. While the ability to sense is an innate part of human beings, human senses can be enhanced via robotic improved sensors. Through a pre-established communication capability, the robot can augment the humans with relevant additional sensor information. The interdependence is only possible if the robot can share this information with the rest of the team. The sensor information would detract from the goal of reduced cognitive load for the humans if the data were presented in a continuous stream. The data need to be filtered so that only applicable information related to detecting the enemy is passed to the team members. To do so, the robot needs to be equipped with sensors that are more capable than its human counterparts. The information gathered by these sensors needs to be relayed to teammates in a clear and concise manner without detracting members from current tasks. To provide this information the raw data needs to be handled in one of two ways. The first would be to have raw data processed onboard the platform and then shared with the rest of the team. The advantage to this method is a lower risk to information fidelity in transit, while the disadvantages are higher processing power and higher energy requirements. The second method would have the data processed off-site and then relayed to the team from that remote location. Advantage to this method is lower processing requirements on the machine which allows more room for continuous processes. The disadvantage would be the communications requirement to process the data, and the risk to information confidentiality, integrity, and availability while in transit.

b. Recognize

Recognizing persons or situations and correlating them to known persons or situations is a challenging task. It requires comparing a database of information to the observed situation. To correctly identify a human as an enemy is difficult for Marines and will be difficult for a machine, through advances in feature recognition and machine

learning may ease this burden. Identifying enemy or friendly persons can rely on small details like body language, posture, or footwear. There is possible interdependence in the validation of correlations. The machine could communicate its assumed information and wait for human validation of its perceived information. In instances where danger is not immediate, such as *observation of the enemy* and *meeting engagement*, teaming is a possibility. Certain instances, such as an ambush, teaming during immediate actions shifts cognitive load onto the human and are a detriment. Investment in data analysis and pattern recognition capabilities could increase the machines ability to perform these tasks independently.

c. Identify Direction of Fire

During an ambush, identifying the direction of incoming fire is a critical step to begin counterattack. Potential for interdependence in this instance relies on the advanced sensor capability afforded to the robot. If robot can pinpoint enemy combatants with finite granularity, it can then assist the other Marines in directing their attention onto those targets. Gunshot detection systems onboard the robot would provide the enemy shooters' range and azimuth. The UTACC system could accomplish this in many ways. One method would be to process the incoming fire information with the detection system, and then use a method or combination of methods to indicate the targets direction to the team. Another potential method would be to have the robot orient on the target, based upon detection systems, and commence firing on the target. Both methods quickly direct the remaining team members onto the target, setting conditions for follow on actions. In both instances, the robot becomes a force multiplier increasing their bid for success during immediate actions.

d. Identify Direction of Movement

Possible interdependence in *Identify direction of movement* within the task of move during a *buddy rush* was identified. It is critical to accomplish this task during a *buddy rush* so that Marines do not cross the bounding partners' line of fire or intended direction of movement. The same interdependence is also possible for the *identify friendly trajectory* capacity in relation to the task of *occupy cover*. In this instance, it is

important to avoid occupation of the same cover as another Marine. Two Marines in the same position are a more valuable target for the enemy. Team members can assist each other by signaling direction of movement through various pre-established means of communication. Less implicit means of communication can occur where the robot predicts the end destination and shortest path to that destination for each fire team member. In a contact scenario, value of human life is paramount, so the robot can be the last to move to better understand the intended location of the team members.

e. Range to the Enemy

Human ability to determine range to a target varies largely due to a myriad of factors. Humans use training and experience to make effective use of this skill in combat situations. The robot, with enhanced sensors, can more consistently provide accurate range reports. The challenge is to develop a sensor or suite of sensors that can provide reliable information through the "fog of war" (standard Marine proverb). Dust, debris, weather, and terrain all affect the ability to determine accurate range. The Marines can assist the robot in determining range by having the robot monitor information of the fire team weapon optics. This scenario identifies teaming possibilities with the robot providing these reports to the humans increasing the efficiency of the team. Being able to effectively compute range, and knowing the effective ranges of the team's weapon systems, the robot can suggest the correct weapon system to engage the enemy.

f. Weapon Status

Under duress, such as enemy contact, attention to detail and specific focus on menial tasks is challenging for humans. In monitoring weapon status, the robot has potential to measure aspects such as remaining ammunition, rates of fire, and barrel temperature. This information can be relayed to the team leader for better employment of the team. The robot is going to be inherently better at storing data than a human being. If the robot could measure remaining ammunition counts, it can store and record this information for use by the team. The robot, with processing power, is going to be able to calculate rates of fire better than a human being. Understanding the doctrinal rates of fire for each weapon system in the team, the robot can indicate to the Marines to speed up or

slow down their rate of fire. The same goes for monitoring its own weapon. The robot can measure barrel temperature and suggest to the team members that it requires a barrel change. The robot can understand effective weapon status and understands which weapons are incapacitated and which are active. The lynchpin to all of the teaming abilities is how the robot will monitor these systems. Without the right set of inputs working to gather data, the information cannot be collated or provided to the fire team.

g. Knowing the Heading of the Patrol

To correctly execute the *break contact* immediate action drill using the clock method, knowing the heading of the unit is essential. The heading of an individual is irrelevant because at any given moment where contact is initiated, the Marines can be oriented in many different directions. Interdependence exists in the directability of the team leader to the other members identifying which direction is the twelve o'clock position. Once each member is aware of the reference direction they can move as appropriate to the newly signaled site. The key component to successfully executing this immediate action drill is effective communication between the team members. Every member must have the same picture of the "clock." The robot can assist the human members by providing a waypoint for the fire team formation to travel to. This would provide a reference heading for the entire group. This also exemplifies the need for a preplanned mission briefing to all members of the team, to generate general situational awareness for the patrol.

h. Other teaming potential

There are other areas for potential interdependence gained by increased situational awareness provided by the robot, facilitated by effective communication methods. These areas include *Identifying friendly trajectory to de-conflict with planned route*, *position to on line*, *identify enemy position*, and *location of friendly forces*. In these instances, direct intervention degrades the individual's and the team's ability to conduct the appropriate immediate action. Therefore, methods improving situational awareness and communication during these occurrences will improve efficiency and team cohesion.

3. Independent

Independent, in the scope of our research, defines requirements that the robot needs to accomplish without team assistance or no team assistance can be provided. For the fire team to meet or exceed current human fire team capabilities, the robot needs to perform these actions with proficiency. Listed below are primary examples of independent functions necessary to complete the required immediate actions. More examples are provided in the IA tables in chapter four.

a. Observe and Avoid Obstacles

To appropriately assume a covered position, Marines identify possible objects that provide protection from enemy fire. Current technology limitations restrict the effectiveness in distinguishing obstacles from the terrain. Variance in terrain results in discrepancies in obstacle detectability, creating inconsistencies. Existing machines observe long grass as an obstacle yet dismiss chairs or like items in their path. Similarly, machines have difficulty distinguishing being rocks and dirt or features lacking defined boundaries. Resource investment is ongoing in this arena and further investment will improve upon this capability. None of the team members can assist one another in the detection of obstacles while still completing their respective requisite tasks. Avoiding obstacles is an independent action and no teaming is possible. Every member must be able to repeatedly and accurate avoid identified obstacles.

b. Move

Move is a task present throughout all immediate actions of a fire team. All team members must be capable of independent movement given the required path. No opportunity for support relationships exist.

c. Identify Size of Obstacles

Finding cover, as defined in this paper, is a three-step process. The first step in finding cover in a contact scenario, the Marine must identify obstacles between their current position and the enemies' position. The performer must not only avoid obstacles that would impede movement but also find obstacles that provide protection from enemy

fire. In contact situations such as ambush, where the enemy is producing high volumes of accurate fire on your position, the fire team members cannot assist one another. Occupying cover must be a reflective action, because exposure to this type of fire increases the chance of becoming a casualty. Only once the Marine is in cover can they assist other team members in finding cover. This affords no ability for teaming between fire team members. In a non-kinetic situation, the enemy has not identified the patrol or is not firing at the patrol, there are possible teaming opportunities for identifying obstacles. A team member with a better vantage has potential to point out sources of cover for the other member.

The second step in finding cover is to determine the size of the obstacle. This is to ensure that the obstacle is large enough to shelter the Marine from incoming fire. Selection of an obstacle that exposes the Marine to enemy fire fails the test of adequate cover. In a contact scenario with incoming fire, a Marine is unable to assist another Marine because of the immediate danger. Each member must be capable of independently determining obstacles that fit minimum dimensions for acceptable coverage. No possibility exists for interdependence.

d. Identify Composition

The final step in finding cover, prior to occupying cover, is to identify the material composition of the object. This is a crucial step in determining if the cover will or will not provide adequate protection from enemy fire. Objects that validate the first two steps can invalidate the final step and not qualify as cover. For example, a large bush between the Marine's position and the enemy will pass the first to qualifications for cover. However, the composition of the object will allow rounds to pass through. If a Marine takes cover behind an object with insufficient composition to stop rounds, the risk of becoming a casualty increases. Current robotic systems have difficulty in determining composition of objects, if they can determine it at all. When seeking cover actions must be decisive and expedient because the reason you *seek cover* in the first place involves enemy contact and likely enemy fire. A possible mitigation for this deficiency is providing armored protection to the robot. This does not come without drawbacks, but it

would allow protection for the robot while the human members can find cover. Once in cover, the humans can now direct the robot to a sufficient covered location.

e. Identify Lines of Fire

When traversing ground in a contact situation it is essential to avoid lines of fire. Marines should never cross friendly lines of fire and only cross enemy lines of fire if no other option is available. If a firing line is crossed, the chances of becoming a casualty are at their highest. To avoid this situation team members must be able to identify and avoid firing lines. To complete this task, the Marine needs to identify the origin of the shot as well as its intended destination. This is a unique situation for each Marine in the fire team based upon their position. When identifying enemy lines of fire and the entire fire team comes under fire, no member can mutually support the other. Assistance can be provided if only part of the fire team comes into contact. The member(s) then can identify and inform the other team members where the direction of fire is coming from. When determining the lines of fire for friendly forces, SOPs and TTPs can prevent human beings from intersecting lines of fire. For the robot, a sensing ability for gunshot detection as mentioned above can vastly improve its ability to identify lines of enemy fire. Sensors on the fire team's weapons, as mentioned in the *weapon status*, can provide information on round impact locations. Without incorporating additional sensors, the robot can execute a correlation algorithm that takes the enemy position and the fire position and draws lines of fire between them. As far as immediate action drills are concerned, the enemy's target will be the fire team and vice versa.

4. Planning

One recurring theme that arises in our research is the precondition that the robot (and Marines) have a plan. While Marines have an established planning process before they embark on a mission, it is crucial that the robot also have a plan, one that not only the robot can understand and reason on, but is also understood by the Marines. While Rice et al. (2015) provide considerable detail on how this might occur, it is worth mentioning that none of the aforementioned analysis and robotic actions can occur without it. For example, in the recognize capability IA table, the robot must have some

sort of input as to what the enemy might look like from an auditory or visual stored picture. Also, the robot must know the pre-established communication capabilities to be used on the mission. There are many other planning factors that must be considered before any expectation can be made that a robot would respond appropriately to an immediate action.

C. FUTURE RESEARCH

Current robotic systems are not as capable as humans in activities concerning immediate action drills. Our research and analysis show that the replacement of a human with a machine, using current technology, would reduce the overall capability of the fire team. We have developed a list of possible research topics that would further the UTACC system development.

1. Continued Analysis of Immediate Actions

There is potential for interdependence analysis for any of the other immediate action drills. Additionally, tasks that we have specified in this paper can be further broken down and analyzed. Both endeavors will provide valuable results for future development and implementation of the UTACC program.

2. Robot as an Addition to the Four-Man Fire Team

One possible approach would be to change the robot’s implementation in the fire team. Instead of replacing a member, the robot would be an augment to the four-man construct increasing the fire team strength to five. The robot could be an addition providing a wider range of sensor capabilities and as well as an additional weapon system. Part of this research could be framed around developing new fire team formations with five team members and two light machine guns.

3. Robot as QRF

Another implementation change could be utilizing the robot as a small unit quick reaction force (QRF). The team could call when required and the machine could carry selected variations of combat capabilities.

4. Make the Robot the Base of the Formation

Another implementation change to doctrine could involve the robot serving as the base of the formation. It would use preplanned information to move throughout the battlespace relieving some of the current difficulty in the robot following the varied path of its human teammates. The machine could be utilized as a pack mule and carry larger items for the team assisting it as it moves along its mission path. These are a few areas that could lead to implementation of current systems for the benefit of the team.

5. COMSEC Requirement

The amount of communication between the team members, and potentially with off-site locations, is enormous in making the system deployable. In environments where network exploitation is increasing, protecting this method of communication becomes critical. Research into protecting the information at rest, in transit, and in use is vital to implementation on the battlefield. The same considerations are present concerning RF contested arenas. This research would extend the UTACC original red team research.

D. CHAPTER SUMMARY

From our analysis, independent or interdependent relationships came down to two recurring themes. The first theme revolved around time as a commodity. In situations where time was afforded, interdependence could be maximized. In situations where danger to individuals and the team was higher, time was not available, and therefore independence was crucial. The second theme of situational awareness was evident in the amount of required communication between team members. Interdependence is not possible without effective and efficient communication. For successful implementation of machines and humans in a fire team, both interdependent and independent capabilities are required. Developing foundational abilities mentioned above creates a launch point for implementation as required by Marine Corps doctrine.

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